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Seasonal variation in the biochemical compositions of phytoplankton and zooplankton communities in the southwestern East/Japan Sea

Naeun Jo[a], Jae Joong Kang[a], Won Gyu Park[b], Bo Ram Lee[b], Mi Sun Yun[a], Jang Han Lee[a], Su Min Kim[c], Dasom Lee[a], HuiTae Joo[a], Jae Hyung Lee[a], So Hyun Ahn[a], Sang Heon Lee[a,*]

[a] *Department of Oceanography, Pusan National University, 2, Busandaehak-ro 63beon-gil, Geumjeong-gu, Busan 46241, Republic of Korea*
[b] *Department of Marine Biology, Pukyong National University, 45, Yongso-ro, Namgu, Busan 48513, Republic of Korea*
[c] *National Institute of Fisheries Science, Korea, Busan 46083, Republic of Korea*

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ABSTRACT

The macromolecular composition of phytoplankton communities and the proximate composition of zooplankton communities were measured monthly in the southwestern East/Japan Sea from April to November 2014 in order to identify seasonal changes in, and relationships among, the biochemical compositions in both phytoplankton and zooplankton. The carbohydrate content of phytoplankton was highest in June, whereas the protein content was highest in August and lipids were highest in April. Overall, carbohydrates were dominant (53.2 ± 12.5%) in the macromolecular composition of phytoplankton during the study period. This composition is believed to result from the dominance of diatoms and/or nutrient-depleted conditions. In comparison, the protein level of zooplankton was highest in November, whereas lipids were slightly higher in May than other months. Overall, proteins were the dominant organic compounds (47.9 ± 8.6% DW) in zooplankton communities, whereas lipids were minor components (5.5 ± 0.6% DW). The high protein content of zooplankton might be related to the abundance of copepods, whereas the low lipid content might be due to a relatively high primary production that could provide a sufficient food supply for zooplankton so that they do not require high lipid storage. A significant positive correlation (r=0.971, n=7, $p < 0.01$) was found between the lipid compositions of phytoplankton and zooplankton during our study period with a time lag, which is consistent with the findings from previous studies. More detailed studies on the biochemical composition of phytoplankton and zooplankton are needed to better understand the East/Japan Sea ecosystem's response to the many environmental changes associated with global warming.

1. Introduction

The East/Japan Sea is a semi-marginal sea located between the East Asian continent and the Japanese Islands. Previous studies have reported that the East/Japan Sea is a productive region with regards to primary production (Kwak et al., 2013; Joo et al., 2014). The southwestern region is especially characterized as a highly productive region compared with other regions of the East/Japan Sea (Yamada et al., 2005; Yoo and Park, 2009; Lee et al., 2014). According to Hyun et al. (2009) and Yoo and Park (2009), coastal upwelling and eddies could be the main reasons for the high productivity in this southwestern region. Additionally, Onitsuka et al. (2007) found that the nitrogen flux supplied by the Tsushima Warm Current (TWC) through the western channel of the Korea/Tsushima Strait sustained the high primary production in the southwestern East/Japan Sea.

Over the past 50–60 years, the East/Japan Sea has undergone dramatic environmental changes (Kim and Kim, 1996; Gamo, 1999; Kang et al., 2003a, b). For example, the temperature has increased by 0.1–0.5 °C in the upper 1000 m, and this warming has been accompanied by the deepening of the oxygen minimum layer from a few hundred meters to below 1500 m (Kim and Kim, 1996; Kim et al., 2001; Kang et al., 2003a, b). These changes in ocean temperature and chemistry may alter the physiological function, behavior and productivity of organisms and consequently lead to shifts in the size structure and seasonal abundance of populations (Doney et al., 2012). In particular, the quantitative and qualitative changes at lower trophic levels (i.e., phytoplankton and zooplankton) caused by recent environmental changes could lead to considerable changes in marine ecosystems through the food web. Phytoplankton, as major primary producers, constitute the basis of food webs (Falkowski and Raven, 2007), and zooplankton occupy a key ecological position in the pelagic food web, which transfers the energy and matter produced by phytoplankton

* Corresponding author.
E-mail address: sanglee@pusan.ac.kr (S.H. Lee).

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and the microbial loop to higher trophic levels (Azam et al., 1983; Sherr et al., 1986; Harris et al., 2000). Studies have reported changes in phytoplankton and zooplankton under recent environmental conditions in the East/Japan Sea (Kang et al., 2004; Lee et al., 2004; Yamada et al., 2004; Chiba et al., 2008; Kang, 2008; Shim et al., 2008; Kim et al., 2010, 2014 Rho et al., 2010). However, these studies mainly focused on quantitative changes (e.g., abundances, biodiversity) in phytoplankton and zooplankton communities. There have been no previous studies of qualitative changes (i.e., biochemical composition) of the phytoplankton and zooplankton communities that are basic food sources in the East/Japan Sea, though the biochemical composition of phytoplankton can be changed by various environmental factors (Suárez and Marañón, 2003). Furthermore, the biochemical composition of phytoplankton has important trophic implications because this composition affects the nutritional quality of food available for aquatic herbivores (Boëchat and Giani, 2008). Therefore, understanding the changes that occur in the biochemical composition of phytoplankton and zooplankton could provide important information about their nutritional status and potential effects on higher trophic levels in marine ecosystems.

The main aims of this study are to (1) improve our knowledge of the seasonal variation in the biochemical composition of phytoplankton and zooplankton (2) determine the main factors regulating the biochemical composition of phytoplankton and zooplankton, and (3) determine the relationship between the biochemical compositions of phytoplankton and zooplankton in the southwestern East/Japan Sea.

2. Materials and methods

2.1. Study sites and sampling

The study was conducted onboard the *R/V TAMGU 12* in the southwestern East/Japan Sea (129.4~130 °E, 35.7~36.6 °N) at monthly intervals from April to November 2014 (Fig. 1). A total of 21 stations were selected for oceanographic sampling. Water samples were collected in 5 or 10 L Niskin bottles (Part no. 101005, General Oceanics, Inc.) on conductivity-temperature-depth (CTD) oceanic profilers to obtain multilayer water samples and physical properties such as water temperature and salinity. To assess the macromolecular composition of phytoplankton, water samples were collected at three different light levels (100%, 30% and 1% penetration of surface irradiance; called: three light depths), which were determined using a Secchi disk. The zooplankton samples were collected using a Bongo net (60 cm mouth diameter, 333 μm mesh size) in a double oblique tow from the surface to near the bottom. To determine the volume of water passing through for a quantitative analysis of the zooplankton per volume, the bongo net was equipped with a flow meter (Hydro-bios model 438115, Kiel, Germany) attached to the net mouth.

2.2. Chlorophyll a concentration

The discrete water samples used to examine the chlorophyll *a* (chl-*a*) concentration were obtained from the surface to near the bottom depth. Water samples were filtered using 25 mm GF/F filter papers (Whatman, 0.7 μm pore) to measure the total chl-*a* concentration. To obtain the size-fractionated chl-*a* concentration, the samples were passed sequentially through 20 μm and 2 μm membrane filters (47 mm), followed by 47 mm GF/F filters (Whatman, 0.7 μm pore). Filtered samples for chl-*a* analysis were extracted overnight in 90% acetone in the dark (Parsons et al., 1984), and the chl-*a* fluorescence in the acetone extract was then measured using a 10 AU fluorometer (Turner Designs, Sunnyvale, CA, USA). The chl-*a* levels were measured as described in Parsons et al. (1984).

2.3. Macromolecular composition of phytoplankton

To analyze the macromolecular composition (carbohydrates, proteins and lipids) of phytoplankton, the water samples were filtered through a 47 mm GF/F filter and stored at -80 °C until further analysis in the home laboratory. A spectrometer (Labomed, Los Angeles, CA, USA) was used for spectrophotometric analysis. The carbohydrate concentration was determined using the phenol-sulfuric method described by Dubois et al. (1956) and by measuring the absorbance of samples at 490 nm and comparing this with a glucose standard (1 mg mL^{-1}, 108 SIGMA) curve. The protein content was measured using the method described by Lowry et al. (1951) and by absorbance at 750 nm using a protein standard solution (2 mg mL^{-1}, SIGMA). Lipids were extracted using a modification of the methods described by Bligh and Dyer (1959) and Marsh and Weinstein (1966) with chloroform and methanol (1:2, v/v). The absorbance at 360 nm was compared to a tripalmitic acid standard curve. The Weinberg (1971) equation was used to calculate the calorific value of phytoplankton as a food source (Fabiano et al., 1993, 1996).

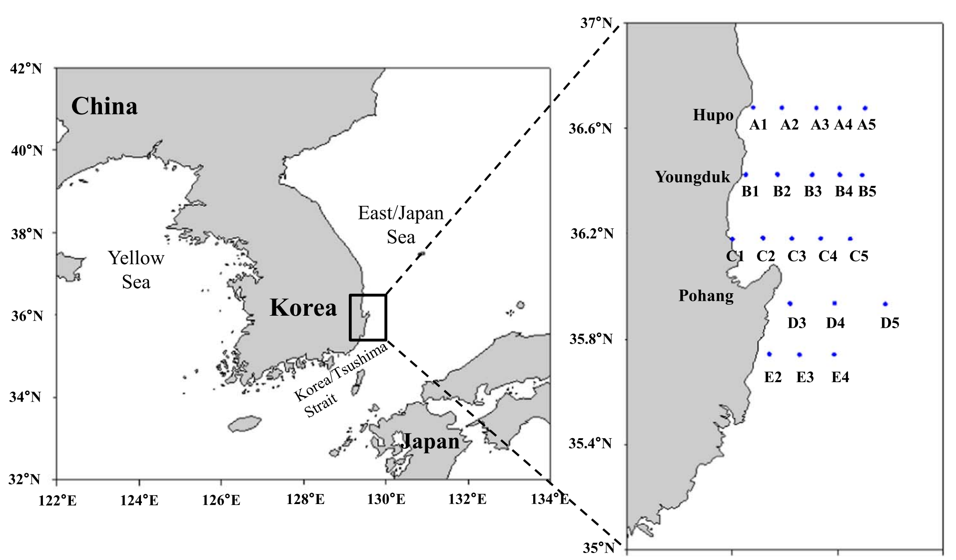

Fig. 1. Locations of sampling stations in the southwestern East/Japan Sea, 2014.