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Interannual variability of the phytoplankton community by the changes in vertical mixing and atmospheric deposition in the Ulleung Basin, East Sea: A modelling study

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ABSTRACT

The East Sea (Japan Sea) ecosystem has experienced a significant warming and ever-increasing anthropogenic atmospheric deposition of nitrogen during recent decades. To understand the impacts of such environmental changes on the planktonic community, we set up a zero-dimensional European Regional Seas Ecosystem Model (ERSEM) in the Ulleung Basin, East Sea for the years 2001–2012. The model results show that as the winter maximum mixed layer depth (MMLD) changes, the growth and grazing loss of phytoplankton functional types (PFTs) are affected differently, resulting in differential success of PFTs in the upper mixed layer. Diatoms pre-empted the early spring growth by better utilization of light and nitrate. Diatoms' advantages lessened as the MMLD decreased. Flagellates and picophytoplankton showed mixed responses to decreased MMLD. Their net primary productivity (NPP) and peak biomass decreased but their annual biomass increased due to decreased grazing. Dinoflagellates always did better when MMLD decreased. The model results also indicate that with an increase in atmospheric deposition, the picophytoplankton and the flagellates increased in summer, whereas the dinoflagellates and the diatoms decreased. For the study period, the atmospheric deposition in the Ulleung Basin increased the annual net primary production by 4.58% (mean; range 3.77–10.58%). Biological variables showed the largest responses in summer with high year-to-year variability. Picophytoplankton increased the most (summer increase mean: 23.23%; summer increase range: 9.12–42.6%) while dinoflagellates decreased the most (summer decrease mean: −2.33%; summer decrease range: −9.09 to 10.13%). The changes in flagellates and diatoms were much less. Taking the results together, it is likely that as the warming and atmospheric deposition continue to intensify into the future; the phytoplankton community in the region will shift to smaller phytoplankton with consequent changes of food web structure to follow.

1. Introduction

The composition of the phytoplankton community plays an important role in controlling marine biogeochemical cycling and primary production (Doney et al., 2002; Falkowski et al., 2003). The phytoplankton groups have different nutrient requirements and utilization methods (Falkowski et al., 2004; Litchman et al., 2007; Jennings et al., 2008; Finkel et al., 2009) and are grazed by different zooplankton groups (Sterner and Elser, 2002). For example, diatoms transport carbon to the deep ocean through rapid sinking and have a great effect on carbon export production. Their frustules are an important determinant of the silicon cycle (Smetacek, 1999). Diatoms are also an important food web element supporting large fish populations. Therefore, it is important to predict present and future changes in phytoplankton community composition to understand how the marine ecosystem is influenced by environmental changes such as warming and anthropogenic forcing.

In recent decades, climate warming and the increase in anthropogenic nutrient inputs to surface waters have been major issues in the oceans. Recent models have begun to include many different phytoplankton functional types (PFTs) and zooplankton

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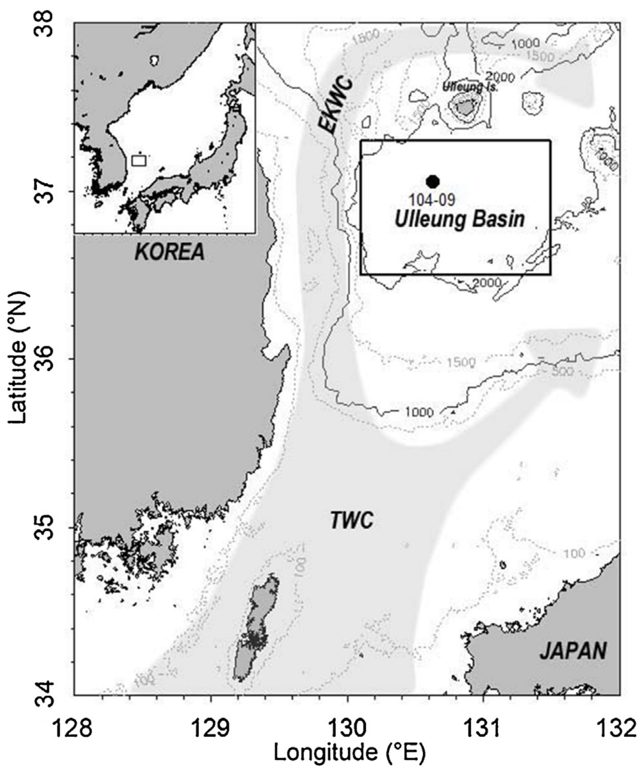

Fig. 1. Map of the study area with bathymetric contours. The black circle indicates 104–09 station (37°N, 130.6°E) of the KODC. The rectangular box shows the model domain. The shaded arrows denote major currents of the area—TWC: Tsushima Warm Current, EKWC: East Korean Warm Current.

functional types (ZFTs) in an attempt to understand the effect of these marine environmental changes on the marine ecosystem and biogeochemical cycling. Several studies have suggested that microphytoplankton were reduced when the mixed layer depth (MLD) became shallower in the north-western Mediterranean basin (Auger et al., 2014) and large phytoplankton such as diatoms might decrease as the vertical mixing is attenuated by climate warming (Lewandowska et al., 2014). The atmospheric nitrogen inputs entering the open ocean could increase the primary production and the effects of increasing atmospheric deposition are expected to continue to grow in the future (Duce et al., 2008).

The East Sea (Sea of Japan), surrounded by the Korea Peninsula, Japan and Russia, is a semi-enclosed marginal sea of the northwestern Pacific (Fig. 1). It has some features characteristic of the ocean, such as thermohaline circulation, western boundary current, meso-scale eddies and coastal upwelling, so it is sometimes referred to as a “miniature ocean” (Ichiye, 1984). The East Sea has also undergone two major marine environmental changes over the last several decades and can serve as a model case to study the impacts of the two major decadal changes mentioned above. Firstly, the East Sea has been in a warming trend in the upper 1000 metres since the late 1980s (Kim et al., 2001). Like other mid-latitude regions, vertical mixing is a dominant source of nutrient supply in the East Sea (Yentsch, 1990; Dugdale et al., 1992; Onitsuka and Yanagi, 2005). If the vertical mixing in the middle latitudes decreased through climate warming, it would limit the nutrient supply and decrease the total phytoplankton near the surface (Doney, 2006). Secondly, the N^* (the relative abundance of N over P on the basis of the N:P ratio, 13:1) has steadily increased in the surface waters since the 1980s (Kim et al., 2011b). Kim et al. (2011b) suggested that the atmospheric deposition by Asian NO_x emission related to rapid industrialization might have caused the increase in N^*. The increase in anthropogenic nitrogen inputs to surface waters might bring about changes in the N:P ratio and eventually influence the marine ecosystem.

Despite the evident decadal environmental changes, the responses of the East Sea ecosystem have not been adequately studied. Most studies have focused on the spatial and temporal variability in the biomass of total phytoplankton or some groups mainly due to the lack of long-term observation of phytoplankton community composition. These studies put forward hypotheses about the key physical processes that underlie the variability (Kim et al., 2000, 2007; Yamada et al., 2004, 2005; Chiba et al., 2008). The lack of detailed observation has prompted the use of ecosystem models to test hypotheses about the marine environmental changes affecting the phytoplankton community composition. Nutrient-phytoplankton-zooplankton-detritus (NPZD)-type models have been used in some studies to understand the seasonal variations of the phytoplankton blooms and nutrients dynamics (Onitsuka and Yanagi, 2005; Onitsuka et al., 2007, 2009). These models have only one nutrient component, nitrogen, and one or two phytoplankton groups, so they cannot take account of the complex dynamics of PFTs and ZFTs.

In this study, we used a zero-dimensional European Regional Seas Ecosystem Model (ERSEM) whose structure includes four nutrient elements, four PFTs and three ZFTs to understand the dynamics of the phytoplankton community clearly and to look more deeply into the biological processes. The key questions that we address are: (1) how do the changes in vertical mixing and atmospheric deposition alter the phytoplankton community composition and the primary production? (2) what is the relative contribution of the major sources to the annual nutrient supply?

2. Data and methods

2.1. Data sources

In order to investigate the interannual variability of PFTs, the station 104–09 (37.0°N, 130.6°E) of the Korea Ocean Data Center (KODC), located in the middle of the Ulleung Basin, was selected as a representative site of the model domain (Fig. 1). At this station, there are various available data including long-term oceanographic

Table 1
Data sources for model input or validation.

Data	Data provider	Description
Chlorophyll *a* concentration	Ocean Biology Processing Group, National Aeronautics and Space Administration (NASA)	Point (37.0°N, 130.6°E), 2001–2012, monthly reconstructed data using Ocv6 algorithm
HPLC pigment	Korea Institute of Ocean Sciences & Technology	Points (36.5–37.3°N, 130.1–131.5°E), 2000–2010, survey data
Temperature	Korea Ocean Data Center	Point (37.0°N, 130.6°E), 2001–2012, 0–400 m bimonthly survey data
Salinity	Korea Ocean Data Center	Point (37.0°N, 130.6°E), 2001–2012, 0–400 m bimonthly survey data
Cloud cover	Korea Meteorological Administration	Point (37.5°N, 130.9°E), 2001∼2012, daily survey data
Nutrients for vertical mixing	Korea Institute of Ocean Sciences & Technology	Points (36.5∼37.3°N, 130.1–131.5°E), 2000–2010, 0–1500 m survey data
Nutrients for atmospheric deposition	Literature reviews	Uno et al. (2007); Zhang et al. (2011); KMA (2013)