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Vertical variation of pelagic ciliate communities in the western Arctic Ocean

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ABSTRACT

The vertical distribution and structure of pelagic ciliate communities were investigated at 32 stations (western Arctic Ocean) in a summer sea-ice reduction region from August 1 to September 10, 2012. The distributions of species number, abundance, biomass, dominant species number and abundance, and structural diversity indices showed clear vertical trends associated with vertical changes in the water column. In addition, vertical patterns in community structure accurately reflected those environmental conditions. Multivariate correlation analysis demonstrated that vertical variation in ciliate communities was significantly related to a series of environmental variables. Community structure parameters, especially Shannon diversity (H') and Margalef richness (D), showed strong relationships with vertical changes in chlorophyll *a* and might provide better predictors in future studies. Furthermore, heterotrophic and mixotrophic assemblages both demonstrated clear vertical distribution patterns, and microzooplankton have shown significantly relationship with chlorophyll *a*. These results provide basic data on vertical variation in ciliate communities in the western Arctic Ocean and have considerable potential to understand how pelagic ciliates structured in water column.

1. Introduction

Ciliates are important components of microplankton communities and play an important role in the transfer of energy and material through the pelagic food web (Sherr and Sherr, 2002, 2009). In marine ecosystems, planktonic ciliates are believed to feed on pico- and nanoplankton, which are the dominant size fractions in terms of biomass and primary productivity (Stoecker and McDowell-Cappuzzo, 1990; Sherr et al., 2013), and are expected to be the main grazers as copepods are unable to crop these size classes efficiently (Marshall, 1973). Although the importance of planktonic ciliate ecology is being increasingly recognized and extensive ecological studies in arctic/sub-arctic waters have been investigated in last decade (e.g., Jensen and Hansen, 2000; Lovejoy et al., 2002; Comeau et al., 2011; Lovejoy and Potvin, 2011; Mironova et al., 2013; Franzè and Lavrentyev, 2014), data regarding vertical variation in pelagic ciliate communities and their relationship with water masses are still scant, particularly in the western Arctic Ocean.

Since the late 1990s, catastrophic sea ice reductions during the summer have been observed in the Pacific sector of the Arctic Ocean (western Arctic Ocean) (Shimada et al., 2006; Serreze et al., 2007). As previous studies have shown, the upper several hundred meters of the Arctic Ocean and adjacent seas, such as the Chukchi Sea, are strongly stratified (e.g., Bates et al., 2005). With decreasing sea ice, these regions might experience increased phytoplankton production and diversity compared to ice-covered areas because of the intensification of light in the water column (Lee and Whitledge, 2005) and increased wind-induced mixing, which replenishes sea surface nutrients (e.g., Carmack et al., 2006). Therefore, the distributions of water masses and relationships to nutrient distributions and algal biomass have been examined in detail (e.g., Nishino et al., 2008). High pelagic primary productivity provides the basis for enhanced local secondary production (Lee et al., 2010). However, we still cannot predict whether ongoing vertical changes in water column will affect pelagic ciliates because very little is known about ciliates; species-level community observations are particularly lacking in this region. Thus, to better characterize both the pelagic ciliate community in the western Arctic Ocean and factors that influence its composition and structure, samples of ciliates and other biotic and abiotic parameters were collected from 32 profiles during the late

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summer in a region of melting sea ice. The resulting data were used to provide a more complete picture of the ciliate community in the western Arctic Ocean.

The main objectives of this study were to characterize the vertical distribution of planktonic ciliates, reveal vertical patterns in community structure, determine their potential relationship with water environmental condition, and try to determine factors that influence the vertical distribution of ciliates in the western Arctic Ocean.

2. Material and methods

2.1. Study stations

A multidisciplinary survey was conducted onboard the Korean icebreaker *Araon* in the Chukchi Sea and east Siberian Sea of the western Arctic Ocean, encompassing the area from the Mendeleyev Ridge to the Chukchi Borderland (including the Chukchi Plateau and Northwind Ridge) during late summer from August 1 to September 10, 2012 (Fig. 1). 32 sampling stations were visited (Fig. 1).

2.2. Sampling and sample processing

In total, 227 samples were collected from the 32 stations during the cruise. Vertical profiles of seawater temperature, salinity, density of water, and dissolved oxygen were obtained using a CTD/Rosette system (SeaBird Electronics, SBE 911+) at each sampling station in a depth gradient of 0 m, 10 m, 20 m, 40 m, 60 m, 75 m, 100 m and 150 m.

Water samples for nutrient analysis were collected using the CTD/Rosette sampler holding 24 10-l Niskin bottles. Nutrient samples (100 ml) for measuring nitrate+nitrite (NO_2+NO_3), ammonium (NH_4), phosphate (PO_4), and silicate concentrations (SiO_2) were analyzed onboard the ship using a Bran and Luebbe model Quatro AA (Auto Analyzer), according to the manufacturer's manual.

Water samples (500–1000 ml) for total chlorophyll *a* (Chl *a*) concentration were taken from each depth and immediately filtered through glass fiber filter paper (47 mm; Gelman GF/F). Concentration of Chl *a* was measured onboard using a Turner design trilogy fluorometer after extraction with 90% acetone (Parsons et al., 1984).

To determine the abundance of ciliates, a Niskin Rosette sampler was used to take water samples from each depth. For quantitative studies and the identification of ciliates, 500-ml seawater samples were fixed with Lugol's iodine solution (4% final concentration, volume/volume) (Yang et al., 2009, 2010); these were then stored at 4 °C in darkness until analysis (Pitta et al., 2001; Kchaou et al., 2009; Choi et al., 2012; Yang et al., 2012). Preserved samples were allowed to settle in the mass cylinder for at least 48 h. The upper water was then siphoned off, leaving 20 ml. 1 ml aliquot of each concentrated sample was placed in a Perspex chamber and the ciliates were counted under a light microscope at magnifications from 200× to 400×. Ultimately, 50 ml of seawater was examined to assess abundance. Tintinnids were identified using lorica morphology and the species descriptions of Kofoid and Campbell (1929, 1939); other naked ciliates were identified to the lowest possible taxonomic group or morphologically similar taxa following references such as Maeda (1986), and internet sources (e.g., Strüder-Kypke and Montagnes, 2002). Trophic preference of ciliate was also taken from these sources because the fixative made it impossible to differentiate between heterotrophic or mixotrophic taxa. The taxonomic scheme used was according to Lynn (2008).

The biovolumes of naked ciliate cell or tintinnid lorica were determined from measurements of their linear dimensions and the volumes were calculated from standard geometric shapes (Hillebrand et al., 1999) and carbon content estimated from relationships described in Menden-Deuer and Lessard (2000). Hereinafter, the term biomass refers to carbon biomass.

2.3. Data analysis of samples

The biodiversity parameters species diversity (Shannon-Wiener H'), species evenness (Pielou's J') and species richness (Margalef D) were computed following the equations:

$$H' = -\sum_{i=1}^{S} P_i(\ln P_i)$$

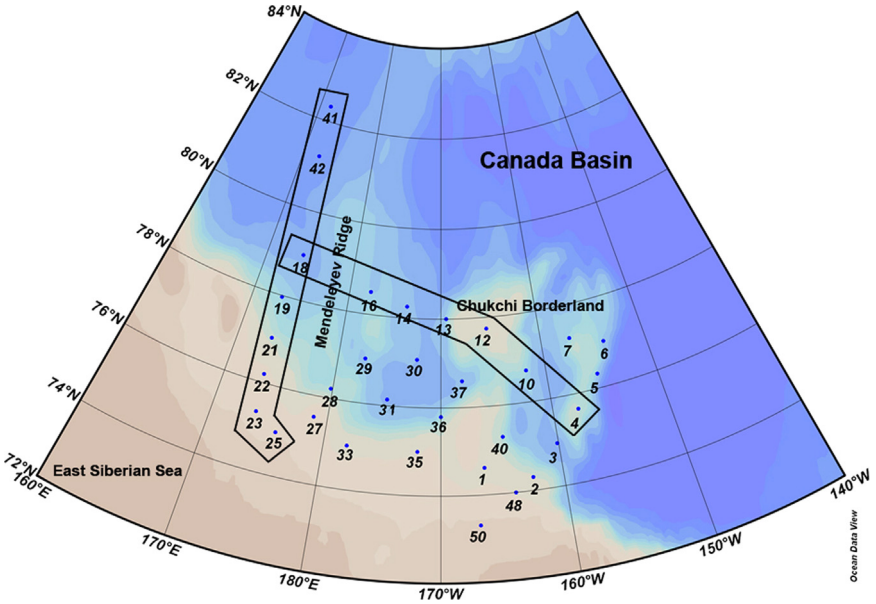

Fig. 1. 32 Sampling stations in western Arctic Ocean from August 1 to September 10, 2012. Samples are coded for stations. Map produced using Ocean Data View (Schlitzer, 2003).