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# Can pelagic ciliates indicate vertical variation in the water quality status of western Arctic pelagic ecosystems?

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ABSTRACT

The vertical pattern of pelagic ciliate communities was observed at eight layers in the Chukchi Sea and the northern Bering Sea of the western Arctic Ocean during the summer sea-ice reduction period (August 5 to August 24, 2016). A total of 44 ciliate species were identified, with seven species dominated the communities in the water column. Multivariate and univariate analyses demonstrated that: (1) community structures of ciliates vary significantly among eight water depths; (2) variations in the vertical distribution of ciliates were significantly correlated with changes in physicochemical variables, especially the ammonia; (3) the distributions of the three dominant species were significantly and positively related to the chlorophyll *a* and ammonia concentrations; and (4) species richness and abundance were significantly and positively correlated with the concentrations of ammonia and chlorophyll *a*. These results suggest that pelagic ciliates may reflect vertical variations in the water quality status of western Arctic ecosystems.

## 1. Introduction

Pelagic ciliates are important components of the microplankton fauna in marine ecosystems (Finlay et al., 1979, 1988; Sherr and Sherr, 1987; Caron and Goldmann, 1990; Zhu et al., 2012; Jiang et al., 2013, 2014, 2015, 2016; Yang et al., 2016). They play crucial roles in community function and ecosystem processes by mediating the flux of carbon and energy from pico- and nanoplanktonic producers to higher trophic levels (Stoecker and McDowell-Cappuzzo, 1990; Sime-Ngando et al., 1995; Yang et al., 2004, 2009, 2010, 2012, 2016; Xu and Xu, 2017; Xu et al., 2017; Zhong et al., 2017). Ciliates' short life cycles and rapid responses to environmental changes have allowed standardization of observations for spatial and temporal comparisons, and thus they have been employed widely as a bioindicator for bioassessment of water quality in marine ecosystems (Cairns et al., 1972; Kchaou et al., 2009; Jiang et al., 2011, 2013; Xu et al., 2014; Xu and Xu, 2017; Xu et al., 2017; Zhong et al., 2017).

Since the late 1990s, catastrophic sea-ice reductions have had notable effects on plankton production and diversity during summer in the Pacific (western) sector of the Arctic Ocean (Coachman and Barnes, 1961; Shimada et al., 2001, 2006; Nishino et al., 2008; Dolan et al., 2012). Previous studies have shown that phytoplankton production and diversity may increase significantly in these regions compared with ice-covered areas due to an increase of light in the water column and greater wind-induced mixing, which replenishes nutrients at the sea surface (e.g., Dolan and Coats, 1990; Carmack et al., 2006; Lee and Whitledge, 2005; Nishino et al., 2008). Thus, pelagic primary production can significantly influence the vertical distribution of microzooplankton, such as pelagic ciliates (Springer et al., 1989; Lee et al., 2010; Jiang et al., 2014, 2015, 2016). Although Jiang et al. (2015) reported variations in pelagic ciliate community patterns, the usefulness of pelagic ciliates as an indicator for the monitoring of vertical changes in water conditions in polar areas remains undetermined.

In this study, environmental drivers of vertical variation in pelagic ciliate communities were studied based on a dataset from one cruise in the western Arctic Ocean. Our objectives in this study were: (1) to demonstrate the spatial patterns of community structures and biodiversity at various water depths, (2) to identify the relationships between ecological features of pelagic ciliates and environmental conditions, and (3) to confirm the potential of ciliates as a bioindicator for the assessment of vertical variation in water conditions in the western Arctic Ocean.

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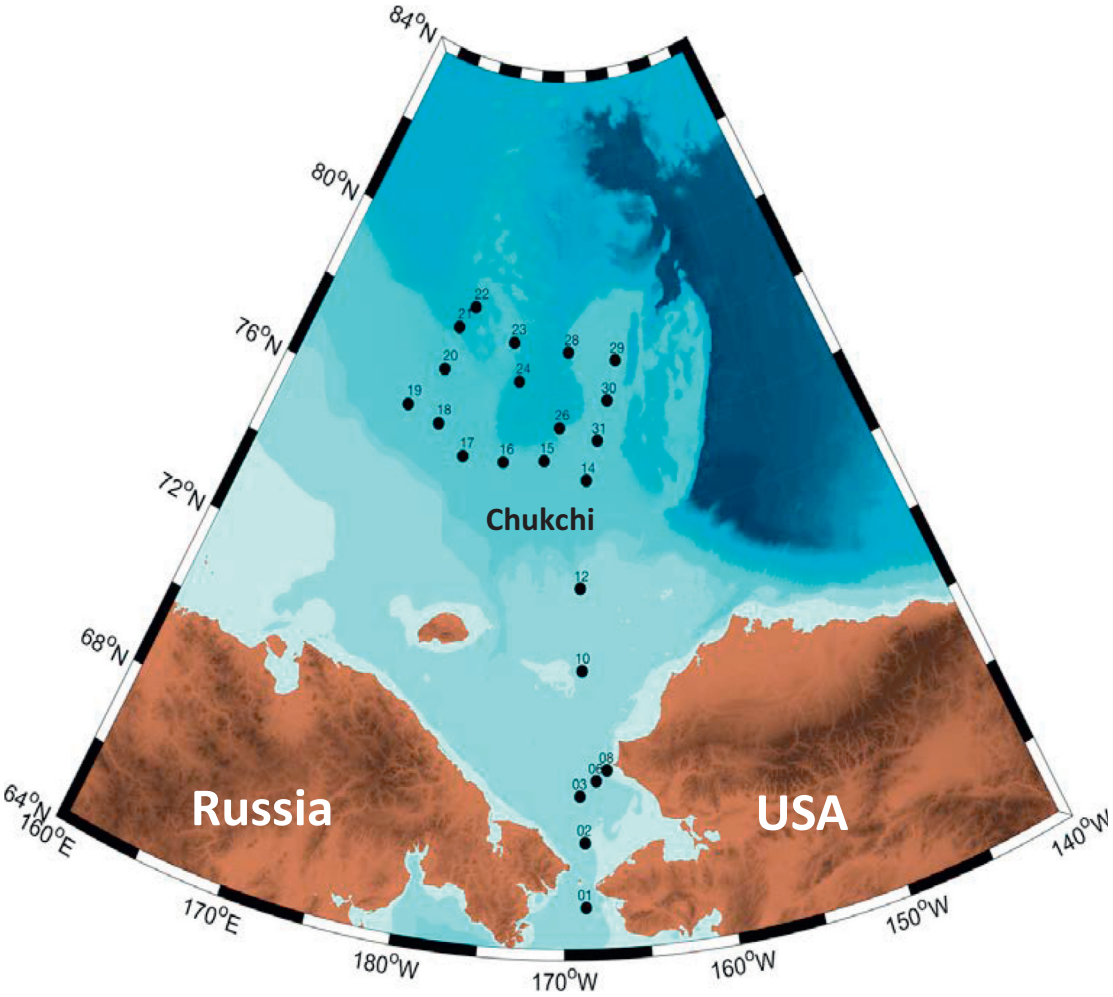


**Fig. 1.** Sampling stations of the Korean icebreaker Araon in the Bering Sea and Chukchi Sea of the western Arctic Ocean, encompassing an area extending from the Mendeleyev Ridge to the Chukchi Borderland (including the Chukchi Plateau and Northwind Ridge), August 5–24, 2016.

## 2. Materials and methods

### 2.1. Study stations

A multidisciplinary survey was conducted onboard the *IBRV* Araon in the northern Bering Sea and the Chukchi Sea of the western Arctic Ocean, encompassing an area extending from the Mendeleyev Ridge to the Chukchi Borderland (including the Chukchi Plateau and Northwind Ridge) during summer (August 5–24, 2016; Fig. 1). A total of 23 sampling stations were visited (Fig. 1).

### 2.2. Sampling and sample processing

In total, 85 samples were collected from 23 stations during the cruise. Vertical profiles of seawater temperature, salinity, density of water, and dissolved oxygen (DO) were obtained using a CTD rosette system (SBE 911 +; Sea Bird Electronics), which was deployed at each station in a depth profile from the surface to 200 m. Water samples for nutrient analysis were drawn from the CTD rosette sampler, which consists of 24 10-l Niskin bottles, into 50-ml conical tubes and stored immediately in a refrigerator at 2 °C until analysis. Ammonium ($NH_4$), nitrite + nitrate, ($NO_2$ + $NO_3$), phosphate ($PO_4$), and silicic acid [Si $(OH)_4$] were measured onboard within 3 days of sampling using a four-channel continuous auto-analyzer (QuAAtro, Seal Analytical) according to Joint Global Ocean Flux Study protocols. Water samples (300–500 ml) for total chlorophyll *a* (Chl *a*) measurement were collected from each depth and filtered immediately through glass fiber filters (47 mm; Gelman GF/F). Concentrations of Chl *a* were measured onboard using a Turner Trilogy fluorometer after extraction with 90% acetone (Parsons et al., 1984). To determine the abundance of ciliates, a Niskin rosette sampler was used to collect water samples from each depth; 500-ml seawater samples were fixed with Lugol's iodine solution (4% final concentration, volume/volume) and then stored at 4 °C in darkness until analysis (Pitta et al., 2001; Kchaou et al., 2009; Choi et al., 2012; Yang et al., 2016). Preserved samples were allowed to settle in a graduated cylinder for at least 48 h. The upper layer of water was siphoned off, leaving 20 ml of concentrated sample. A 1-ml aliquot of each concentrated sample was placed in an acrylic chamber, and the ciliates were counted under a light microscope (Olympus BX51) at magnifications of 200–400 ×. Tintinnids were identified based on lorica morphology using the species descriptions of Kofoid and Campbell (1929, 1939); other ciliates were identified from references such as Montagnes and Lynn (1991) and Song et al. (2003). The taxonomic scheme of Lynn (2008) was used.

### 2.3. Data analyses

Multivariate analyses were carried out using PRIMER software (v. 7.0.13; Clarke and Gorley, 2015). The species distributions were summarized using clustering analysis on matrices of “index of association”