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# Spatial patterns in pelagic ciliate community responses to various habitats in the Amundsen Sea (Antarctica)

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ABSTRACT

To investigate the impacts of climate change on environmental conditions and pelagic biodiversity, spatial patterns in pelagic ciliate communities were studied at 18 stations from five habitats in the Amundsen Sea (western Antarctic) during austral summer from December 2010 to January 2011. Clear spatial patterns were observed in community structure, and significant differences were found among the various habitats. The species number, abundance, biomass and biodiversity indices (Shannon diversity $H'$, Pielou's evenness $J'$, and Margalef richness $D$) also showed clear spatial trends. Pelagic ciliate community structure accurately reflected environmental variability. Alone or in combination, several primary environmental variables were found to affect community spatial patterns in specific habitats. Shannon $H'$ and Margalef $D$ showed strong relationships with spatial changes in chlorophyll *a* and might be better predictors in future Antarctic studies. This study presents the first detailed description of spatial patterns in pelagic ciliate communities and their correlations with environmental variability in habitats in the Amundsen Sea during early austral summer. Our findings provide detailed and basic data on the composition, distribution, and variation of ciliate communities in the Amundsen Sea, and will help answer important questions about polar ecosystems.

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## 1. Introduction

As a part of the Southern Ocean located off Marie Byrd Land, the Amundsen Sea is historically known as a region with a relatively narrow continental shelf and several coastal polynyas that are located adjacent to large ice shelves (Fragoso and Smith, 2012). Sea ice extent in the Amundsen Sea has been decreasing over the last few decades (Arrigo and Alderkamp, 2012; Yager et al., 2012) and primary production studies show that it is probably the most productive area in Antarctica (Yager et al., 2012). Therefore, the Amundsen Sea has been described as one of the most productive and dynamic pelagic systems in Antarctica (Smith et al., 2011). Being the most poorly sampled area of the Southern Ocean, increasing attention has recently focused on this region (Griffiths, 2010; De Broyer et al., 2011; Dolan et al., 2013).

Although limnological and physicochemical variability can be easily measured using modern techniques, instantaneous measurements cannot provide enough information to understand how environmental changes influence the habitat conditions that are experienced by living creatures. Therefore, investigations of biota are still essential (Carmack et al., 2006; Hourston et al., 2009; Xu et al., 2011a; Jiang et al., 2013b,c). In most pelagic ecosystems, planktonic ciliates can form a substantial proportion of microplankton and play a crucial role in the functioning of the pelagic food web (Dolan and Marrase, 1995; Yang et al., 2004; Wickham et al., 2011; Dolan et al., 2013; Jiang et al., 2013a). With their rapid growth and delicate external membranes, ciliates react more quickly to environmental changes than most other eukaryotic organisms (Gong et al., 2005). Stoecker et al. (1994) hypothesized that the taxonomic composition of pelagic ciliates follows the environmental status of the water mass rather than a traditional zoogeographic distribution pattern. Since then, more and more studies have found strong relationships between ciliates and environmental conditions (e.g., Elloumi et al., 2006; Kchaou et al., 2009; Jiang et al., 2011a, 2012a, 2013c; Wickham et al., 2011; Xu et al., 2011a,c, 2013).

Although the importance of planktonic ciliate ecology is being increasingly recognized, studies that combine quantitative abundance and biomass data with good taxonomic resolution for ciliates, particularly in the Southern Ocean, which is experiencing increasing climate influences, are quite rare (Wickham et al.,

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2011). Moreover, previous studies on ciliates in the Southern Ocean have generally concentrated on sea ice/ice edge communities or calculated the total abundance and/or biomass of assemblages (tintinnids or oligotrichs) and have lacked sufficient taxonomic detail to identify the loss of ecologically relevant species (e.g., Song and Wilbert, 2000; Garrison et al., 2005; Santoferrara and Alder, 2009). As far as we know, Wickham et al. (2011) have reported the only existing data that provide a species list, which was pooled from nine stations in Bellinghausen and the Amundsen Sea. Furthermore, the quantitative importance of identifying spatial patterns in pelagic ciliate communities in response to habitat conditions has still received little attention. To improve our knowledge of this biological hot spot and assess environmental heterogeneity in the sea ice melting region, a maiden expedition was conducted by the icebreaker *Araon* in the Amundsen Sea from December 2010 to January 2011.

The primary objectives of this study were to characterize the composition and distribution of pelagic ciliates, determine forcing factors that influence ciliate spatial distributions, reveal spatial patterns in ciliate community structure in various habitats, and investigate linkages between community structure and environmental conditions in habitats.

## 2. Materials and methods

### 2.1. Study stations

A multidisciplinary survey was conducted onboard the Korean Research icebreaker RV *Araon* in the Amundsen Sea between 64 and 74°S during early austral summer from December 2010 to January 2011 (Fig. 1). Conductivity, temperature, and depth (CTD) casts were conducted at 30 stations during the cruise. In the present study, 18 sampling stations were selected from five areas: oceanic stations 27–30 located in open oceanic water; stations 8, 9, 18, 21, and 29 in polynya; transitional area stations 6, 7, 22, 24, and 26 in sea ice areas as connections between oceanic areas and polynya; stations 10 and 11, which were also in polynya but were very close to the edges of the Getz and Dotson glaciers, respectively, and were affected by ice shelf melting and thought to be specific habitat with different environmental conditions and community characteristics than polynya; and sea ice edge stations 16 and 17 as habitats under sea ice to the east and west of the polynya that were thought to be affected by polynya. Areas of sea ice and concentrations were based on data from the National Snow and Ice Data Center in Boulder, Colorado, that corresponded to the cruise period. The classification of habitats follows Yager et al. (2012), Dolan et al. (2013), and Lee et al. (2012, 2013).

### 2.2. Sampling and sample processing

Vertical profiles of seawater potential temperature, salinity, water pressure, and dissolved oxygen (DO) were obtained using a CTD-Rosette system (SeaBird Electronics, SBE-911+) at each sampling station basically following a depth gradient of 0 m, 5 m, 15 m, 25 m, 35 m, 50 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 nitrogen ($NO_2 + NO_3$), ammonium nitrogen ($NH_4$), 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 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).

In total, 130 water samples were collected using a Niskin rosette sampler from depths at 18 stations. For quantitative studies and the identification of ciliates, 500-ml seawater samples were fixed with Lugol's iodine solution (4% final concentration, volume/volume); these were then stored at 4 °C in darkness until analysis (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. A 1-ml aliquot of each concentrated sample was placed in a Perspex chamber and the ciliates were counted under a light microscope (Olympus BX51) at magnifications of ×200 to ×400. Tintinnids were identified using lorica morphology and the species descriptions of Kofoid and Campbell (1929, 1939); other ciliates were identified by performing protargol staining according to Montagnes and Humphrey (1998), and based on the published references to keys and guides such as Montagnes and Lynn (1991) and Strüder-Kypke and Montagnes (2002). The taxonomic scheme used was according to Lynn (2008).

The carbon biomass of ciliate cells was determined from measurements of their linear dimensions and by using volume equations for their appropriate geometric shapes (Winberg, 1971). Conversion factors of carbon biomass were 0.19 pg C $\mu m^{-3}$ for aloricate ciliates and 0.053 pg C $\mu m^{-3}$ for loricate cells (Putt and Stoecker, 1989; Stoecker et al., 1994).

### 2.3. Data analysis of samples

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

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

$$J' = H' / \ln\ S$$

$$D = (S-1)/\ln/N$$

where $Pi$ = proportion of the total count arising from the $i$th species, $S$ = total species, and $N$ = total individuals.

Univariate spearman correlation analyses were carried out using the statistical program SPSS v16.0. Data were log-transformed before analyses.

Multivariate analyses of spatial pattern in ciliate communities were conducted using the PRIMER v6.1 package (Clarke and Gorley, 2006) and PERMANOVA+ for PRIMER (Anderson et al., 2008). The contribution of each species to the ciliate communities was summarized using the SIMPER (Similarity Percentage Analysis) program (Clarke and Gorley, 2006). The spatial environmental status of the 5 habitats was summarized using principal components analysis (PCA) based on log-transformed/normalized abiotic data from 130 samples and differences between groups of samples were tested with the submodule ANOSIM (Clarke and Gorley, 2006). The spatial differences in ciliate communities were summarized using the submodule CAP (canonical analysis of principal coordinates) of PERMANOVA+ with Bray–Curtis similarities from log-transformed species–abundance data and using PERMANOVA to test differences between sample clouds which were separated by two CAP axes (Anderson et al., 2008; Xu et al., 2013). The significance of biota–environment correlations was tested using the routine RELATE (Mantel test). Submodule biota–environment (BIOENV) was used to explore potential multivariate relationships between biotic parameters and the abiotic data (Clarke and Gorley, 2006).

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