Difference of planktonic ciliate communities of the tropical West Pacific, the Bering Sea and the Arctic Ocean

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Abstract

Ciliates are important components in planktonic food webs, but our understanding of their community structures in different oceanic water masses is limited. We report pelagic ciliate community characteristics in three seas: the tropical West Pacific, the Bering Sea and the Arctic Ocean. Planktonic ciliate abundance had "bimodal-peak", "surface-peak" and "DCM (deep chlorophyll *a* maximum layer)-peak" vertical distribution patterns in the tropical West Pacific, the Bering Sea and the Arctic Ocean, respectively. The abundance proportion of tintinnid to total ciliate in the Bering Sea (42.6%) was higher than both the tropical West Pacific (7.8%) and the Arctic Ocean (2.0%). The abundance proportion of small aloricate ciliates (10–20 μm size-fraction) in the tropical West Pacific was highest in these three seas. The Arctic Ocean had higher abundance proportion of tintinnids in larger LOD (lorica oral diameter) size-class. Proportion of redundant species increased from the Arctic Ocean to the tropical West Pacific. Our result provided useful data to further understand ecology roles of planktonic ciliates in different marine habitats.

Key words: planktonic ciliates, vertical distribution, community structure, tropical West Pacific, Bering Sea, Arctic Ocean

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1 Introduction

Oceanic environments varied from the equator to high latitudes. In addition to the obvious decrease in surface water temperature with a progression northward to the pole, the stratification type varied from alpha oceans (subtropical seas stratified by temperature) to beta oceans (high-latitude seas stratified by salinity) (Carmack, 2007). The deep chlorophyll *a* maximum layer (DCM) became shallow in the area between the alpha and beta oceans. It ultimately changed into surface chlorophyll *a* maximum layer as in the Bering Sea (Wolf and Woods, 1988; Sohrin et al., 2010; Arrigo and van Dijken, 2011; Jiang et al., 2015; Burridge et al., 2017).

Biogeographically, plankton distribution can be determined by large gyres (Longhurst, 2007), of which three exist from the northern Pacific Ocean to the Arctic Ocean: the North Pacific Gyre, the Subarctic Gyre, and the Beaufort Gyre (Springer et al., 1996; Longhurst, 2007; Steele et al., 2004, 2011; Hu et al., 2015; Li et al., 2016). In addition to the difference in species composition and abundance in these different habitats, the structure and function of planktonic ecosystems were different (Megrey et al., 2009; Legendre and Niquil, 2013).

Planktonic ciliates belong to the phylum Ciliophora, class

Spirotrichea, and subclasses Oligotrichia and Choreotrichia (Lynn, 2008). They comprise tintinnids with lorica, and aloricate ciliates without lorica. These ciliates are primary consumers of pico-(0.2–2 μm) and nano-(2–20 μm) sized producers, and are important food source for metazoan and fish larvae (Gómez, 2007). Accordingly, ciliates play an important role in material circulation and energy flow, from microbial food webs to the traditional food chain (Azam et al., 1983; Pierce and Turner, 1992; Calbet and Saiz, 2005).

It has been established that different tintinnid taxa dominate each of these gyres (Taniguchi, 1984; Dolan et al., 2014; Li et al., 2016; Wang et al., 2019). There was no study on other community characteristics of ciliates in addition to the taxonomic difference. In this study, we examined community characteristics of ciliates in the tropical West Pacific, the Bering Sea and the Arctic Ocean. The three study areas belong to the three gyres (the North Pacific Gyre, the Subarctic Gyre and the Beaufort Gyre), respectively. We hypothesize that ciliates characteristics differ due to the influence of each gyre. We examine following characteristics of ciliate community: (1) distribution patterns in their vertical direction, (2) abundance proportions of tintinnids to total ciliates, (3)

the abundance proportion of aloricate ciliate size-fractions, and (4) tintinnid abundance proportion of different lorica oral diameter (LOD) size-classes and proportions of tintinnid redundant species in total tintinnids. Our results will assist in understanding differences in vertical distributions of ciliate communities in these three seas, exploit considerable mechanism that how pelagic ciliates structured in water column, and enable prediction of variation in tintinnid community species richness and LOD size-class composition in world oceans.

2 Materials and methods

Planktonic ciliates were sampled during two cruises: one to the tropical West Pacific (12 stations, deeper than 3 000 m) from 28 November to 31 December, 2015 aboard R/V *Kexue* (Fig. 1), and the other to the Bering Sea (5 stations, deeper than 500 m) and the Arctic Ocean (13 stations, deeper than 2 000 m) from 18 July to 10 September, 2016, during the 7th Chinese National Arctic Research Expedition aboard R/V *Xuelong* (Fig. 1).

At each station, temperature and salinity profiles were obtained from the surface to 200 m using a conductivity-temperature-pressure (CTD) sensor (Sea-Bird Electronics, Bellevue, WA,
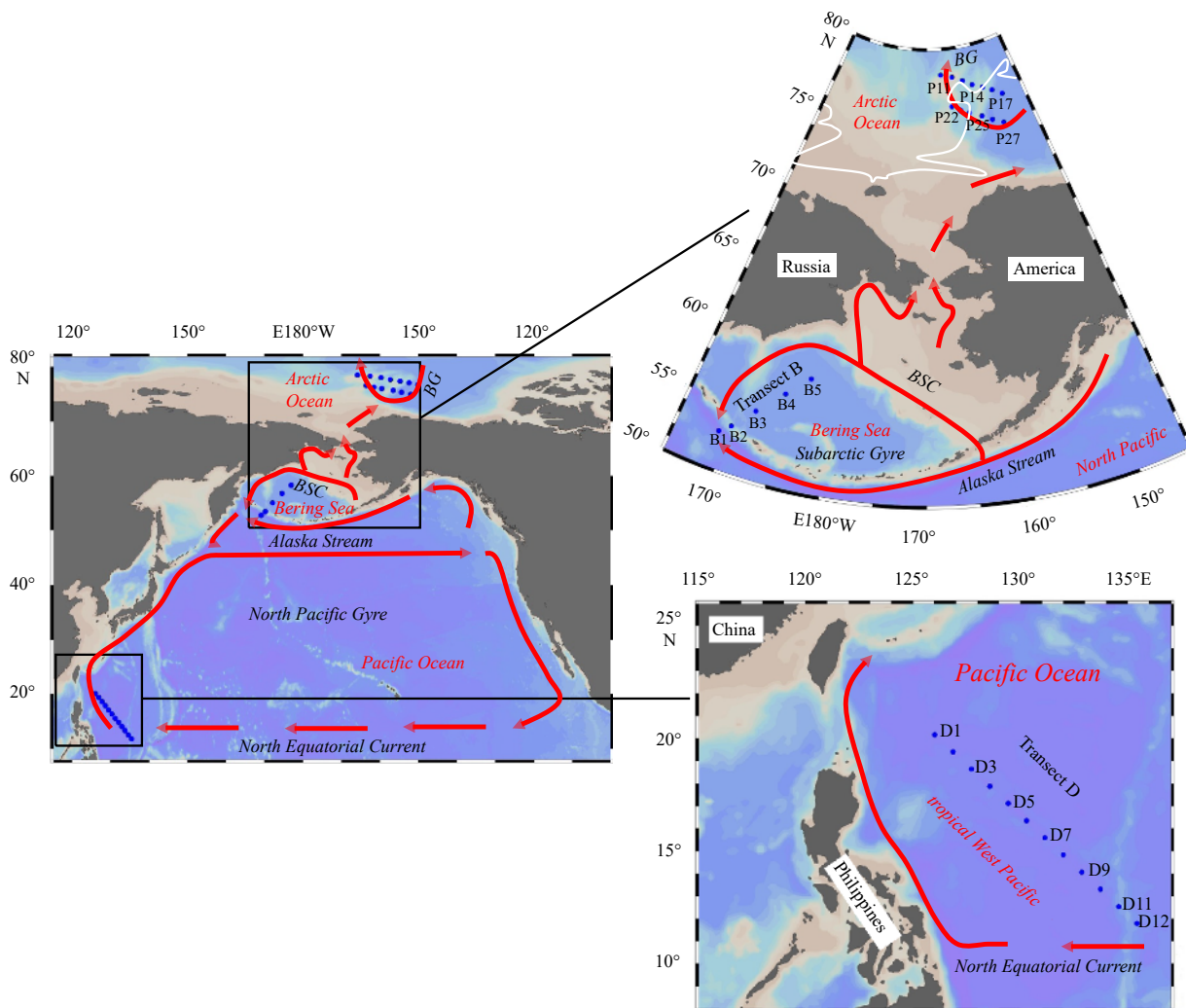

Fig. 1. Survey stations: tropical West Pacific, Bering Sea and Arctic Ocean. White line: 80% sea ice concentrations, 15th August, 2016, according to Sea Ice Remote Sensing at the University of Bremen (https://seaice.uni-bremen.de/sea-ice-concentration/). Arrows depict currents according to Springer et al. (1996), Steele et al. (2004), Longhurst (2007), and Hu et al. (2015). BSC: Bering Sea Current; BG: Beaufort Gyre.

USA). Water samples were collected at seven depths (sampling points) using 12-L Niskin bottles attached to a rosette wheel. Most sampling occurred at the surface (5 m), 30 m, 50 m, 75 m, 100 m, 150 m and 200 m in each station, but sampling within the DCM necessitated some variation in sampling depth.

Chlorophyll *a* (Chl *a*) concentration was determined by filtering 250 mL of seawater through a Whatman GF/F glass fiber filter. Plankton retained on the filter was extracted in 90% (v/v) acetone, and its fluorescence measured according to the JGOFS protocol (Knap et al., 1996) using a Turner Trilogy fluorometer Model 10.

Water samples (1 L) collected from each depth for ciliate enumeration were fixed with 1% acid Lugol's iodine and stored below 4°C in darkness. In the laboratory, samples were concentrated to about 100 mL by gently siphoning off supernatant after settling for at least 48 h. This settling and siphoning processes was repeated until a final concentrated volume of 50 mL was achieved, which was then settled in two Utermöhl counting chambers (25 mL per chamber) (Utermöhl, 1958) for at least 24 h.

The samples in the two chambers was examined using an Olympus IX 71 inverted microscope (100× or 400×). Less-abundant species were counted in two chambers, while high abundance species were counted in one chamber. Because mechanical and chemical disturbance associated with collection and fixation may have provoked detachment of the protoplasma from the lorica (Paranjape and Gold, 1982; Alder, 1999), empty tintinnid loricae were counted as living cells. We acknowledge the possibility that some lorica might have been empty at collection (Kato and Taniguchi, 1993; Dolan and Yang, 2017), and that our abundances might be overestimates.

For each species, size (length, width, according to shape) of the cell (aloricate ciliate) or lorica (tintinnid, especially length and oral diameter) were measured for at least 20 individuals if possible. Aloricate ciliates were categorized into size-fractions in increments of 10 μm for maximum body length for each individual. According to lorica morphology and size, tintinnids were identified to species following Kofoid and Campbell (1929, 1939), Lynn (2008) and Zhang et al. (2012). Ciliate volumes were estimated using appropriate geometric shapes (cone, ball, and cylinder). Tintinnid carbon biomass was estimated using the equation: carbon = lorica volume (μm^3) × 0.053 + 444.5 (Verity and Lagdon, 1984). We used a conversion factor of carbon biomass for aloricate ciliates of 0.19 pg/μm^3 (Putt and Stoecker, 1989).

There was no existing standardized reference to aloricate ciliate size-fraction. Though Marquis et al. (2011) suggested using equivalent spherical diameter (ESD) to calculate microzooplankton communities, but this method does not reveal the exact length of each aloricate ciliate. We categorized aloricate ciliate size-fractions based on measurement of their longest cell length, following Lessard and Murrell (1996), Taylor et al. (2011) and Liang et al. (2018).

Tintinnid lorica length at different life stages might differ greatly (Gold and Morales, 1976), while the lorica oral diameter (LOD) variation was low for the same tintinnid species (Dolan, 2010). Therefore, LOD was used as a proxy for tintinnid size in this study. The tintinnids were divided into different LOD size-classes which were 4 μm apart (12–16 μm, 16–20 μm and so on). Redundant tintinnid species were defined as these species in the same LOD size-classes. If one LOD size-class has species number (n) larger than one, redundant species number of this LOD size-class was n–1. For a tintinnid assemblage, redundant species number is the sum of that in every LOD size-class. Methematically, redundant species number of a tintinnid assemblage

could be calculated as the number of species minus the number of LOD size-classes (Dolan et al., 2016). The proportion of redundant tintinnid species was calculated as the percentage of redundant species number in total species number.

3 Results

3.1 *Hydrographic features*

Surface temperature and salinity decreased from the tropical West Pacific (27.2–28.6°C, 33.8–34.7) to the Bering Sea (10.1–10.5°C, 32.7–33.0), then to the Arctic Ocean (–1.2–0.7°C, 26.5–28.3). Surface average Chl *a* was highest in the Bering Sea ((0.8±0.5) μg/L), and values in the tropical West Pacific and the Arctic Ocean were (0.1±0.0) μg/L and (0.0±0.0) μg/L, respectively (Fig. 2).

Vertical temperature, salinity and Chl *a* concentration profiles differed in the three seas. The thermocline in the tropical West Pacific occurred at about 100 m, much deeper than in the Bering Sea (about 30 m) and the Arctic Ocean (about 5 m). In the Arctic Ocean, a second temperature peak occurred between 50 and 75 m (Fig. 2).

Salinity was stratified with depth, with lower salinity in surface waters of each sea. The magnitude of differences in temperature and salinity between surface waters and those at 200 m differed in the three seas: temperature ranges in the tropical West Pacific (13.9–28.6°C, difference 14.7°C) and the Bering Sea (1.5–11.3°C, difference 9.8°C) were larger than in the Arctic Ocean (–1.6–1.2°C, difference 2.8°C); salinity ranges in the tropical West Pacific (34.3–35.1, difference 0.8) and the Bering Sea (32.8–33.4, difference 0.6) were smaller than in the Arctic Ocean (27.4–33.4, difference 6.0) (Fig. 2).

Chl *a* concentration differed significantly among the three seas. DCM occurred in both the tropical West Pacific ((101±17) m) and the Arctic Ocean ((66±7) m), but not the Bering Sea, where high Chl *a* concentration occurred in the surface (Fig. 2).

3.2 *Ciliate abundance, biomass and vertical distribution*

Basically ciliate abundance and biomass (calculated by carbon) in the Bering Sea (152–3 267 ind./L, 0.3–11.6 μg/L) was larger than in the tropical West Pacific (35–443 ind./L, 0–0.7 μg/L) and the Arctic Ocean (12–1 615 ind./L, 0–4.5 μg/L) (Fig. 3). In the surface layer, average abundances in the Bering Sea ((1 830± 1 046) ind./L) were 5.7 times and 12.0 times higher than those in the tropical West Pacific ((320±88) ind./L) and Arctic Ocean ((153±94) ind./L), respectively (Fig. 4).

Vertical distribution trend of average abundances of ciliates for each depth in the tropical West Pacific, the Bering Sea and the Arctic Ocean differed (Fig. 4). Average abundance had a "bimodal-peak" (high abundance in both surface and DCM layers), "surface-peak" (high abundance in surface layers), and "DCM-peak" (high abundance in DCM layers), in the tropical West Pacific, the Bering Sea, and the Arctic Ocean, respectively (Fig. 4).

3.3 *Abundance proportion of tintinnid to total ciliate*

Generally, tintinnids were not the dominant (abundance proportion >50%) group of planktonic ciliates. However, tintinnids were the dominant group at layers of 50 m and 100 m (abundance proportion 51.7% and 57.0%, respectively) in the Bering Sea. In terms of average abundance proportion in different layers, tintinnids represented 0.0%–18.3% (average 7.8%±3.1%), 3.9%–75.1% (average 42.6%±20.9%), and 0.0%–9.7% (average 2.0%± 2.2%) of all ciliates in the tropical West Pacific, the Bering Sea and the Arctic Ocean, respectively (Fig. 5).
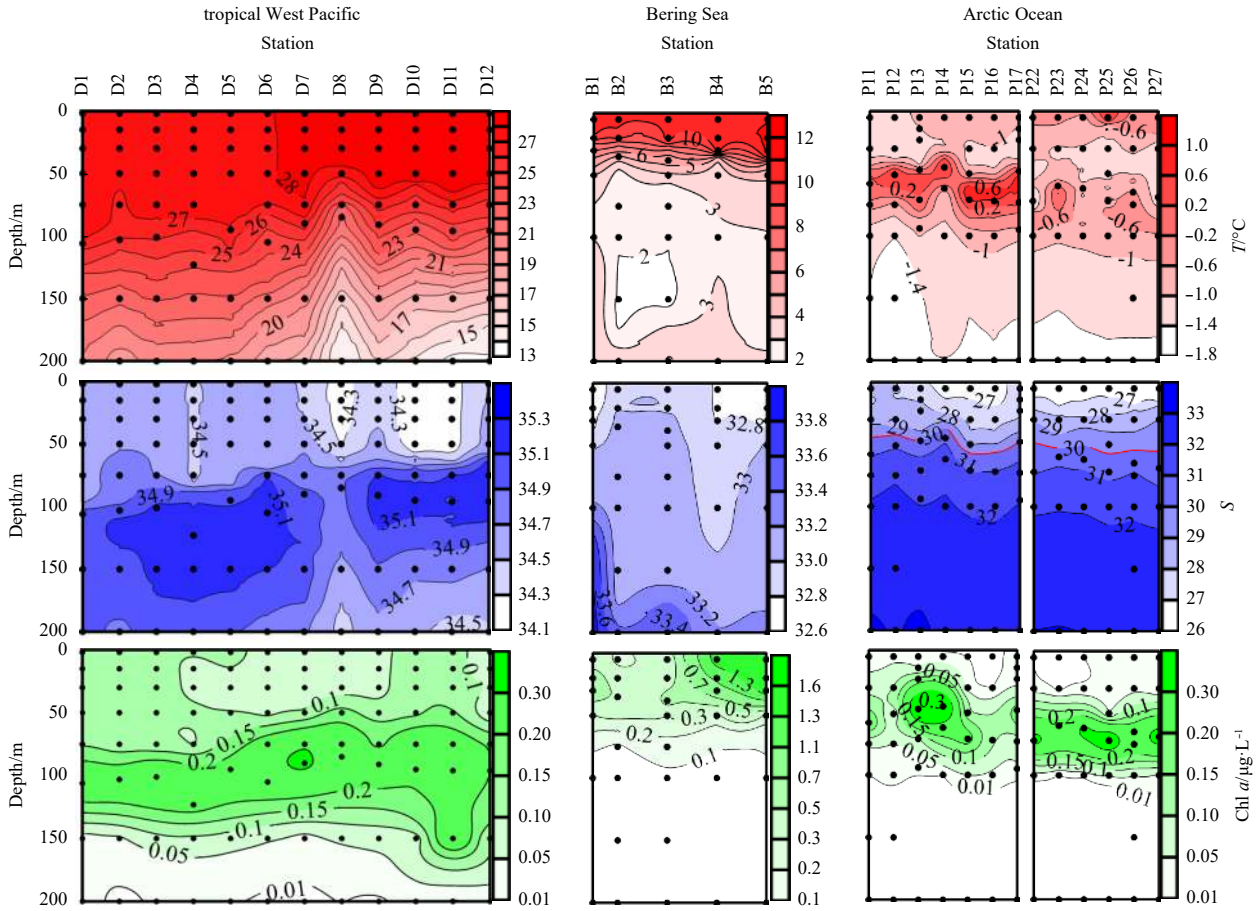
Fig. 2. Vertical distributions of temperature (*T*), salinity (*S*) and Chl *a* concentration from the surface to 200 m in the tropical West Pacific, the Bering Sea and the Arctic Ocean. Black circles: sampling points. Vertical distribution of temperature and salinity in the tropical West Pacific from Wang et al. (2019).
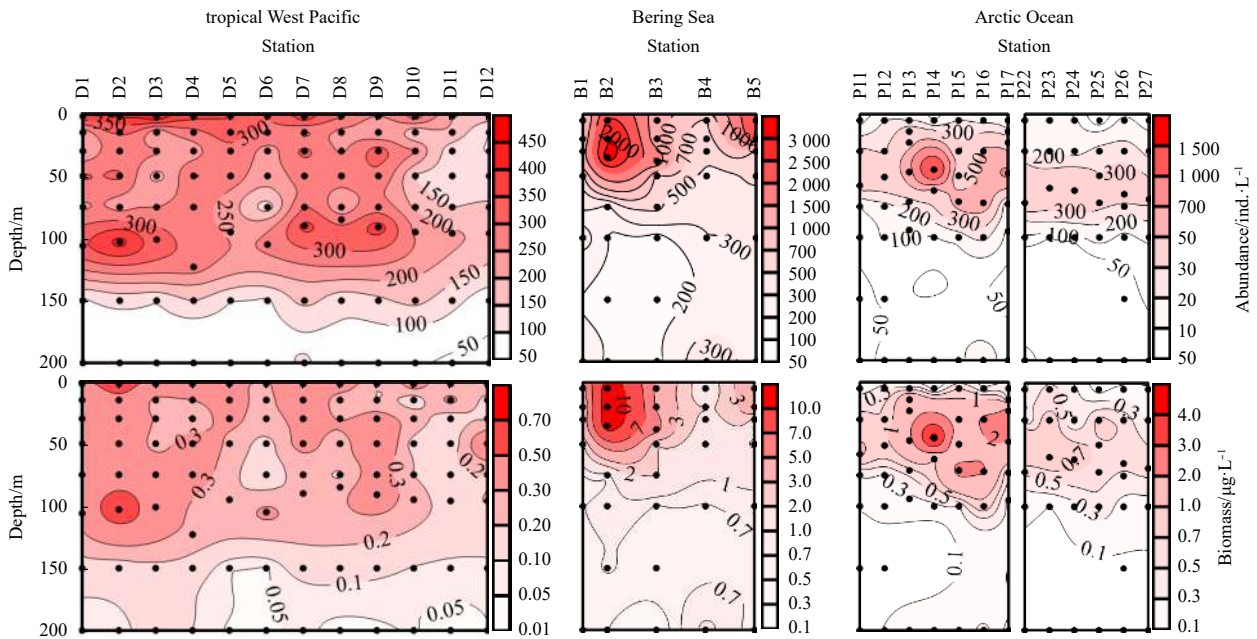

Fig. 3. Vertical distribution of ciliate abundance and biomass from the surface to 200 m in the tropical West Pacific, the Bering Sea and the Arctic Ocean. Black circles: sampling points. Vertical distributions of ciliate abundance and biomass in the tropical West Pacific from Wang et al. (2019).
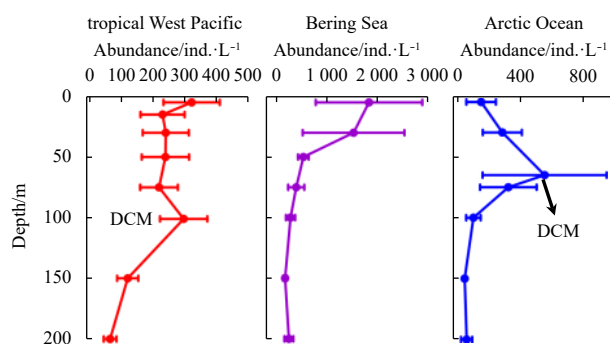
Fig. 4. Vertical distributions of ciliate (total of aloricate and tintinnid ciliates) average abundance for sampling layers in three study areas. DCM: deep chlorophyll *a* maximum layer. Vertical distribution of average ciliate abundance in the tropical West Pacific from Wang et al. (2019).
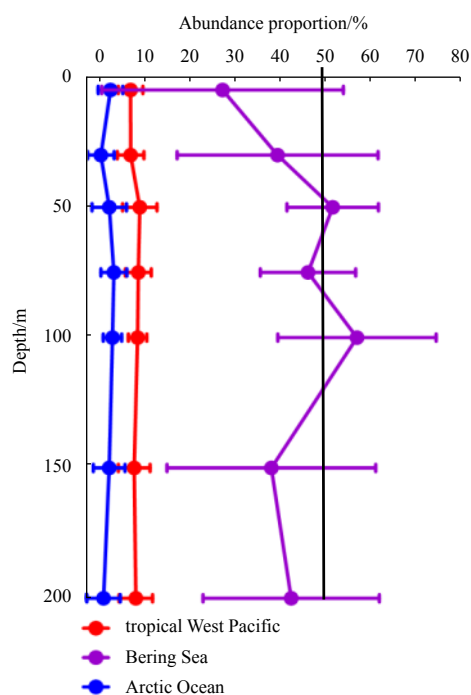

Fig. 5. Average abundance proportion of tintinnids to total ciliates from the surface to 200 m depth in the tropical West Pacific, the Bering Sea and the Arctic Ocean.

3.4 *Aloricate ciliate size-fraction difference*

Abundance proportions of different size-fractions of aloricate ciliates revealed individuals of 10–30 μm size-fractions were more abundant at each depth in the tropical West Pacific than in the Bering Sea and Arctic Ocean (Fig. 6). The 10–30 μm size-fraction in surface waters represented 76.5%±6.8% of aloricate ciliates in the tropical West Pacific, about 20% higher than in both the Bering Sea (54.6%±7.5%) and the Arctic Ocean (56.7%±7.8%). Aloricate ciliates >30 μm size-fraction in surface waters represented less than 30% of all aloricate ciliates in the tropical West Pacific, but more than 40% in both the Bering Sea and the Arctic Ocean (Fig. 6). From surface waters to 200 m depth, aloricate ciliates abundance proportion of 10–20 μm size-fraction were most abundant in the tropical West Pacific, representing more than 40% of all aloricate ciliates. In the Bering Sea and the Arctic

Ocean, aloricate ciliates >30 μm size-fraction were the dominant size-fraction component from surface waters to 150 m depth, but at 200 m the 10–20 μm size-fraction predominated (>40% of all aloricate ciliates) (Fig. 6).

In all three gyres, the abundance proportion of aloricate ciliates in the 10–20 μm size-fraction decreased from surface layers to 75 m (in both the tropical West Pacific and Bering Sea) or 50 m (in the Arctic Ocean), then increased to 200 m depth, while that of the 20–30 μm size-fraction was relatively constant throughout the water column to depths of 200 m. The abundance proportion of aloricate ciliates >30 μm size-fraction first increased from surface waters to 75 m (in both the tropical West Pacific and Bering Sea) or 30 m (in the Arctic Ocean), but then decreased to 200 m in all three water masses. In the layers of 30–75 m, the average abundance proportions of aloricate ciliates >30 μm size-fraction were about 4.4%, 4.9% and 3.8% higher than in surface layers in the tropical West Pacific, the Bering Sea and the Arctic Ocean, respectively (Fig. 6).

3.5 *Lorica oral diameter size-classes and proportion of redundant tintinnid species*

From the tropical West Pacific to the Arctic Ocean, abundance proportion of tintinnids with larger lorica oral diameter (LOD) became higher (Fig. 7). Tintinnid species with LOD ranging 12–16 μm and 24–28 μm size-classes were proportionally most abundant (26.7% and 59.5%) in the tropical West Pacific and the Bering Sea, respectively, while in the Arctic Ocean, tintinnids of LOD 60–64 μm size-class was proportionally most abundant (50.0%) (Fig. 7).

Different seas had different tintinnid species richness patterns in LOD size-classes, and proportions of redundant species. Tintinnids ranging 28–32 μm and 32–36 μm LOD size-classes were the two most species rich size-classes, with 9 and 8 tintinnid species, respectively, in the tropical West Pacific (Fig. 7). Tintinnids of LOD ranging 60–64 μm size-class was the most species rich (3 species) in the Bering Sea. In the tropical West Pacific and Bering Sea there were 48 and 4 redundant species, with the proportion of redundant species being 72.4% and 28.6%, respectively. In the Arctic Ocean, four species were equally distributed in four LOD size-classes, and there were no redundant species.

4 Discussion

4.1 *Planktonic ciliate vertical distribution*

In our study, the distributions of planktonic ciliates in the oceanic area through the water column in the Bering Sea and the Arctic Ocean were revealed to be "surface-peak" and "DCM-peak" patterns, respectively. Though previous studies have not specifically described the patterns in the vertical distribution of planktonic ciliates in either of these two areas, their data revealed that comparable patterns existed: high abundances were reported from surface layers in the Bering Sea (Taniguchi, 1984), and in the Arctic Ocean DCM at 40–80 m (Yang et al., 2015); while a "bimodal-peak" pattern was reported from the Bering Strait to the western Arctic Ocean based on average values (Xu et al., 2018a). The surface peak in Xu et al. (2018a) might be due to high values at shelf stations in the Bering Strait (Matsuno et al., 2014; Yang et al., 2015; our unpublished data), so results of Xu et al. (2018a) may be not representative for the oceanic Arctic Ocean.

Planktonic ciliate vertical distributions have been reported for oceanic waters of the Pacific Ocean (Strom et al., 1993; Leakey et al., 1996; Yang et al., 2004; Gómez, 2007; Sohrin et al., 2010; Zhao et al., 2017; Wang et al., 2016, 2019). However, only Wang et al.
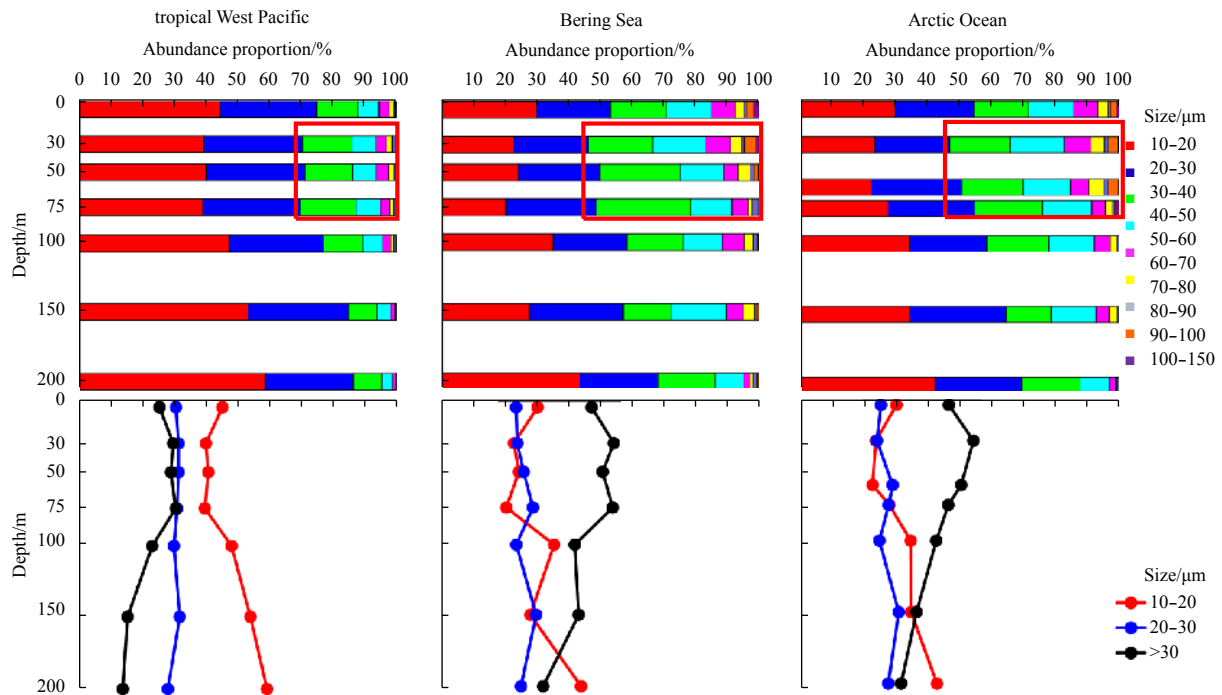
Fig. 6. The abundance proportion of aloricate ciliates different size-class composition (upper) and average abundance (lower) by each layers in the tropical West Pacific, the Bering Sea and the Arctic Ocean. The red dashed box depicts the abundance proportions of aloricate ciliates >30 μm size was greater than those in surface layers.
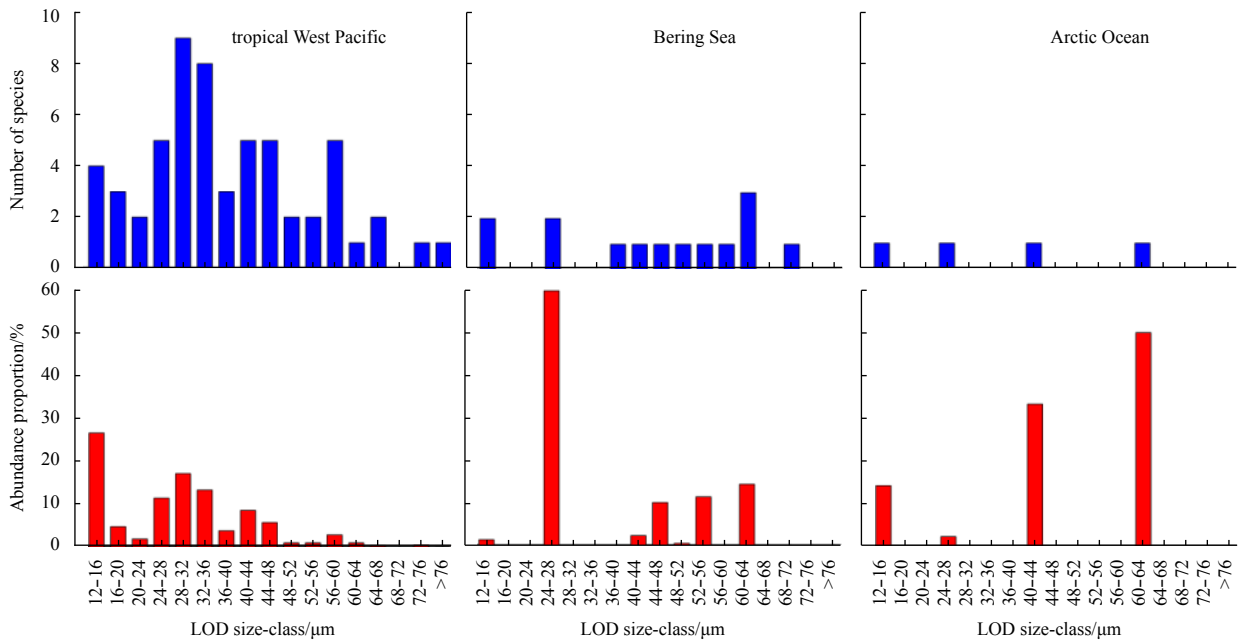

Fig. 7. Number of species and the abundance proportion of each tintinnid LOD (lorica oral diameter, μm) size-class in the tropical West Pacific, the Bering Sea and the Arctic Ocean.

(2019) explicitly described ciliate vertical distribution patterns as having a "bimodal-peak" in the tropical West Pacific.

Several studies have shown ciliate abundance to be positively correlated with Chl *a* concentration (Dolan and Marrasé, 1995; Yu et al., 2013; Jiang et al., 2015; Xu et al., 2018a, b). Our studies showed that there were ciliate peaks in the maximum Chl *a* layer, no matter it is in the subsurface (DCM) or surface layer. Although the tropical West Pacific and the Arctic Ocean had low

Chl *a* concentration in the surface, but there was no surface ciliate peak in the Arctic Ocean as in the tropical West Pacific. We do not know the reasons of this phenomenon because there were differences in surface temperature and salinity between the two areas.

Low salinity in the Arctic Ocean might not be a decisive factor for the low ciliate abundance in the surface layer. In the estuaries such as Changjiang River Estuary, fresh water river discharge

causes low salinity (<30) as well as high Chl *a* and nutrient concentrations in the surface waters (Wang et al., 2013; Zhang et al., 2015). In this case, ciliate in the surface freshwater was higher than in the subsurface layer (Yu et al., 2015).

4.2 *Abundance proportion of tintinnid to total ciliate*

Abundance proportion of tintinnid to total ciliate have been described for tropical and subtropical waters (Fig. 8) (Yang et al., 2004; Gómez, 2007; Sohrin et al., 2010; Wang et al., 2016, 2019). In the tropical West Pacific, average tintinnid abundance proportions varied from 20% (Yang et al., 2004) to less than 10% (Wang et al., 2016, 2019), and in other studies, abundance proportions about 10% in surface equatorial waters to 5% in waters from 10°–15°N (Sohrin et al., 2010). Our result of 7.8% for the tropical West Pacific is comparable to that of Wang et al. (2016) and Sohrin et al. (2010).
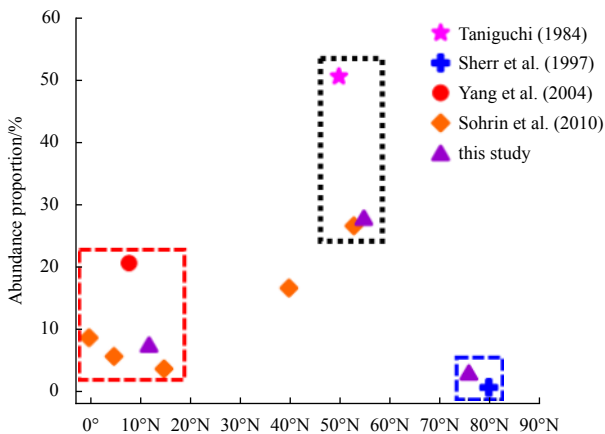

Fig. 8. Abundance proportions of tintinnids to total ciliates in surface layers by latitude. Red dashed box: the tropical Pacific; black dashed box: the Bering Sea; and blue dashed box: the Arctic Ocean.

Abundance proportion of tintinnid to total ciliates were unknown for the Bering Sea and the Arctic Ocean. The abundance proportion (42.6%) in the Bering Sea waters (52°–58°N) in our study was higher than that (25%) for the same latitude (53°N) along 160°W in the subarctic Pacific (Sohrin et al., 2010). We estimate previous abundance proportion (from the surface to 160 m depth) for the Bering Sea based on values in Fig. 2 of Taniguchi (1984) to be about 50%, which is close to our result from this region. The very low value (2.0%) we report for the Arctic Ocean is consistent with Sherr et al. (1997), where tintinnids were reported to be rarely observed from 70°–90°N.

Our data and previous studies showed that the Bering Sea and the Arctic Ocean had the highest and lowest abundance proportion of tintinnids to total ciliates. Until now, environmental factors responsible for these differences were unknown. Loricate ciliates are adapted to high Chl *a* environment where food is sufficient (Suzuki and Taniguchi, 1998). High Chl *a* concentration in the Bering Sea might contribute to the high tintinnid abundance proportion (Fig. 2).

4.3 *Difference in aloricate ciliate size-fractions*

The bathymetric distributions of different size-fractions of aloricate ciliates have been rarely reported from oceanic environments. Ours is the first report of the vertical distribution of aloricate ciliate size-fractions in these three gyres. Our results reveal al-

oricate ciliates <20 μm size-fraction comprise about 45% of all ciliates in surface waters of the tropical West Pacific. This result is consistent with that reported for the northeast equatorial Pacific (5°–11°N), where the average abundance proportion of aloricate <20 μm to total ciliates in the surface was about 50% (Yang et al., 2004), and the Red Sea (29.5°N, depth 650 m), where it was >50% in surface water (Claessens et al., 2008).

No reports of the size-fraction composition of aloricate ciliates in the Bering Sea and the Arctic Ocean are known. In the Prydz Bay (65°–68°S, Southern Ocean), the aloricate ciliates <20 μm size-fraction represented about 40% of the total numbers of aloricate ciliate (Liang et al., 2018), which is both higher than in the Bering Sea and the Arctic Ocean.

We found abundance proportion of aloricate ciliate >30 μm size-fraction in each depth increased from the tropical West Pacific to the Arctic Ocean. The Arctic Ocean has a lower percentage of smaller size-fraction aloricate ciliates. This result supports Bergmann's rule, that, in general, larger-bodied animals tend to live further north than their smaller-bodied relatives (Bergmann, 1847). Some subarctic and subantarctic zooplankton tend to be larger than their relatives in subtropical species (Reid et al., 1978; Martin et al., 2006; Gallienne et al., 2001). For example, species in genus *Euphausia* is 20 mm in body length in subarctic, while it is only 8 mm in subtropical area (Reid et al., 1978).

Why proportionally more larger-sized aloricate ciliates occur in subsurface layers, and more smaller-sized aloricate ciliates occur in deeper waters in all the three areas is unknown in vertical direction. As maximum Chl *a* concentration layers occurred at different depths in the three areas, we speculate that Chl *a* concentration might not be the reason.

4.4 *Variation of dominant lorica oral diameter size-class and proportion of tintinnid redundant species*

Tintinnid LOD (lorica oral diameter) size-class in these three seas has not been previously compared. Dominant tintinnid LOD size-classes have been reported for the Bering Sea (Li et al., 2016) and the Jiaozhou Bay (Feng et al., 2018). Our result that the dominant LOD size-class (24–28 μm) in the Bering Sea is similar to that (22–26 μm) of Li et al. (2016). The space difference in our study that the dominant LOD size-class is large in the cold Arctic Ocean, but small in the warm tropical West Pacific is similar to seasonal changes in dominant LOD size-classes in the Jiaozhou Bay (Feng et al., 2018), where it is larger (48–52 μm) in winter than summer (24–32 μm). Thus, we speculate dominant LOD size-class might be large in cold areas, which might be another aspect of the Bergman's Rule in tintinnids.

Proportions of redundant species in tintinnid assemblages increased markedly from polar to low latitude areas in the northern hemisphere. From 83°N to 37°N, this proportion increased from 0% to 57% (Dolan et al., 2016), while in the Jiaozhou Bay (36°N), this value was 50% all year round (Feng et al., 2018). We found this value to continue increasing with progression from the Arctic Ocean to 15°N, in a linear manner (Fig. 9). Further study is needed to support whether this value will continue to increase southward to equatorial waters.

5 Conclusions

We report changes in ciliate community characteristics in some transects influenced by three gyres (the North Pacific Gyre, the Subarctic Gyre and the Beaufort Gyre). Planktonic ciliates manifest "bimodal-peak", "surface-peak" and "DCM-peak" patterns of bathymetric distribution in the tropical West Pacific, the Bering Sea and the Arctic Ocean, respectively. The abundance
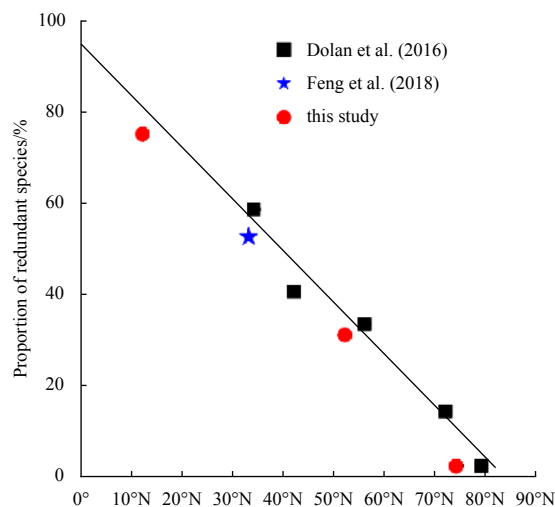
Fig. 9. Relationship between latitude and proportion of redundant species.

proportion of tintinnid to total ciliate increased from the tropical West Pacific to the Bering Sea, then decreased to the Arctic Ocean. Abundance proportion of aloricate ciliate in larger size-fraction increased from tropical West Pacific waters to the Arctic Ocean. Finally, the dominant LOD size-class was small in the tropical West Pacific waters, but large in the Arctic Ocean, with the proportion of redundant species decreasing from the former to the latter. Our results represent a snapshot of ciliate community structure in each gyre, which constitute a baseline for further comparative study on temporal and spatial variation of ciliate communities in the three gyres.

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