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<td>Author(s)</td>
<td>Matsuno, Kohei; Yamaguchi, Atsushi; Fujiwara, Amane; Onodera, Jonaotaro; Watanabe, Eiji; Harada, Naomi; Kikuchi, Takashi</td>
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Seasonal changes in mesozooplankton swimmer community and fecal pellets collected by sediment trap moored at the Northwind Abyssal Plain in the western Arctic Ocean

Kohei Matsu

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Abstract

In the western Arctic Ocean, the long sea ice coverage period prevents year-round seasonal zooplankton sampling by ordinary ship-board observation. To overcome these problems, the analysis of zooplankton swimmers in samples collected by a year-round moored sediment trap may be a powerful tool. In this study, we studied seasonal changes in zooplankton swimmer community and fecal pellets collected by a sediment trap moored at fixed depths (180-260 m) of the Northwind Abyssal Plain in the western Arctic Ocean from October 2010 to September 2012. The fecal pellets were separated into four types: oval, cylinder, spherical and brown-colored pellets. The occurrence of brown-colored pellets was limited to the open water period (July-August) and reached 80% of the total at that time. Ship-board experiments showed that the brown-colored fecal pellets were egested by amphipods (Themisto libellula). The high occurrence of brown-colored fecal pellets during the open water period might be a reflection of the massive feeding activity of amphipods. Zooplankton swimmer flux ranged from 35-739 ind. m⁻² day ⁻¹, and poecilostomatoid copepods were the most abundant (accounted for 69% of the annual mean). Seasonally, barnacle and bivalve larvae were abundant during August-September and August-November, respectively. These meroplanktonic larvae were considered to be transported by current flow from the southern continental shelf, whereas they were absent from summer to autumn in 2012. The annual changes in meroplanktonic larvae occurrence would be a reflection of the annual changes in water mass formation at the upper layer of the sediment trap moored station.

Key words: meroplanktonic larvae, amphipods, sediment trap, fecal pellets, western Arctic Ocean

Introduction

In the western Arctic Ocean, a drastic reduction in the sea-ice extent has been observed during the summer (Stroeve et al., 2007; Comiso et al., 2008; Markus et al., 2009), and the effects of this reduction on the marine ecosystem are cause for concern (Grebmeier, 2012). While the zooplankton community is important, year-round ship-board observation is impossible in the Arctic basin because of the seasonal ice coverage (which lasts for eight months). In the basin of the western Arctic Ocean, annual cycle in abundance and distribution of dominant copepods is reported based on ice station observation (Ashjian et al., 2003). However, most information on the zooplankton community in the western Arctic Ocean has been derived from net-samples collected during the limited open water summer season (Hopcroft et al., 2010; Matsumo et al., 2012). Because of this shortcoming, seasonal changes in the zooplankton community and their grazing intensity in the Arctic Ocean are not fully understood.

A sediment trap can collect sinking materials throughout the year, and zooplankton swimmers and their fecal pellets are also included in the samples (Buesseler et al., 2007). On some occasions, the zooplankton active flux exceeded the passive particle flux and reached > 10 times of the passive flux mass in the Arctic Ocean (Sampei et al., 2009a, 2009b). Because of their importance, seasonal changes in the zooplankton community in the Arctic Ocean were evaluated by analyzing swimmer samples collected with sediment traps at several regions, especially in the Beaufort Sea (Forbes et al., 1992; Ota et al., 2008; Makabe et al., 2010). Recently, seasonal changes in the population structure and life cycle of the dominant copepods were also evaluated around the Northwind Abyssal Plain (Matsumo et al., 2014, 2015).

Zooplankton fecal pellets have an important role in the ver-
tical material flux (Turner, 2002). The morphology (size, shape and color) of the fecal pellets varies with the egested taxa/species (Hansen and Bech, 1996; Urban-Rich et al., 1998). Thus, seasonal changes in the composition of the morphology of the fecal pellet could be treated as indices of seasonal changes in the grazing intensity of various zooplankton taxa in upper layers. Previously, the carbon flux estimation of fecal pellets was reported in the Arctic Ocean during winter (Sampei et al., 2009b). However, little information is available for seasonal changes in the morphology of the fecal pellets.

In the present study, we studied the seasonal changes in a zooplankton swimmer community and fecal pellet morphology based on the samples collected by a sediment trap moored at the Northwind Abyssal Plain in the western Arctic Ocean over two years (from October 2010 to September 2012). In this study, additional ship-board fecal pellet egestion experiments were conducted on each dominant zooplankton species/taxa. The identification of species/taxa was made for the fecal pellets based on their morphology using this reference data.

**Materials and Methods**

**Field sampling**

Samples were collected by sediment trap (SMD26 S-6000, open mouth area 0.5 m², Nichiyu Giken Kogyo Co. Ltd., Tokyo, Japan) rotated at 10-15 days intervals and moored at 180-260 m of St. NAPt (Northwind Abyssal Plain trap, 75°00´N, 162°00´W) from 4 October 2010 to 28 September 2011 (first year) and from 4 October 2011 to 18 September 2012 (second year) (Fig. 1). The end of the trap rope was fixed to the sea bottom (bottom depth: 1,975 m). The sample cups were filled with 5% buffered formalin before deploying the sediment trap.

After retrieving the trap, the 52 samples were sieved gently with 1 mm mesh, and 1/10 subsamples of the passed fraction (<1 mm size) were filtered through a polycarbonate membrane filter, dried and weighed with an analytical balance to calculate the total mass flux (ng dry mass [DM] m⁻² day⁻¹) (Onodera et al., 2015). As supplemented environmental information, the depth and temperature at the sediment trap were monitored every hour. The current speed at St. NAPt was estimated by a physical ocean general circulation model: the Center for Climate System Research Ocean Component Model version 4.9 (cf. Watanabe et al., 2015). Weekly data on the averaged percentage of ice coverage around St. NAPt (74.5-75.5°N, 161.5-162.5°W) during the mooring period were calculated from the sea ice concentration data set (http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS/.nmc/.Reyn_SmithOIv2/, Reynolds et al., 2002). Daily chlorophyll a data, measured by MODIS/Aqua at 9 km resolution, were smoothed by calculating a 9-day running mean.

**Microscopic analysis**

All fractions of > 1 mm and 1/10 fractions of < 1 mm samples were used for the identification and enumeration of zooplankton taxa/species under a stereomicroscope. The species identification of the copepods mainly followed Brodsky (1967), Heron et al. (1984) for Oncaea spp., Frost (1974) for Calanus spp., Miller (1988) for Neocalanus spp. and Frost (1989) for Pseudocalanus spp.

The flux \( F \) (ind. m⁻² day⁻¹) of the zooplankton swimmers were calculated with the following equation:

\[
F = N \times \frac{1}{0.5} \times \frac{1}{d}
\]

where \( N \) is the number of individuals (ind.), 0.5 is the mouth area (m²) of the sediment trap and \( d \) is the sampling interval (days).

The fecal pellets that occurred in the <1 mm fraction samples were categorized into four morphological types (oval, cylinder, spherical and brown-colored) and enumerated under a dissecting microscope. The size of each fecal pellet was measured for the longest axis of the fecal pellet (fecal pellet length) by using an eyepiece micrometer with a precision of 0.01 mm.

**Data analysis**

The zooplankton flux data \( F \) (ind. m⁻² day⁻¹) for each species was log transformed \( \log_10[X+1] \) prior to analysis to reduce the bias of flux. Similarities between the samples were examined using the Bray–Curtis index. For grouping the samples, the similarity indices were coupled with hierarchical agglomerative clustering using a complete linkage method (Unweighted Pair Group Method using Arithmetic
mean: UPGMA) (Field et al., 1982). To identify the species most responsible for the similarity between the zooplankton community groups, tests by SIMPER analysis were performed based on the abundance data. All of these analyses were conducted using PRIMER v6 software (PRIMER-E Ltd.). Inter-group differences in the zooplankton flux were tested by a one-way ANOVA and Tukey-Kramer Test. These statistical analyses were conducted using StatView v5 software (SAS Institute Inc.).

**Ship-board experiment**

For the zooplankton fecal pellet egestion experiments, fresh zooplankton was collected by vertical tows of a ring net (mouth diameter 80 cm, mesh size 335 µm) at 12 stations in the Chukchi Sea during July and September 2013 (Table 1, Fig. 1). After collecting the samples, 10% v/v soda (saturated CO₂ in water) was added immediately to avoid gut evacuation. Fresh zooplankton were sorted by each taxonomic group and decapod larvae (hermit crab). After several-hours incubation, fecal pellets were collected by Pasteur pipette, preserved with 5% v/v borax-buffered formalin and stored in a refrigerator. In the laboratory, morphotype identification and length measurement were made for each fecal pellet following the same procedure mentioned above.

### Table 1. Information of ship-board experiments in the western Arctic Ocean during July-September 2013.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Position</th>
<th>Net towed depth (m)</th>
<th>Taxa/species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lat. (ºN)</td>
<td>Lon. (ºW)</td>
<td></td>
</tr>
<tr>
<td>7 July 2013</td>
<td>65-29</td>
<td>168-55</td>
<td>Bl, Cg, Eb, Nc, Np, Tl</td>
</tr>
<tr>
<td>10 July 2013</td>
<td>69-48</td>
<td>166-19</td>
<td>Bl, Cg, Eb, Eu, Np, Tl, Ov</td>
</tr>
<tr>
<td>12 July 2013</td>
<td>70-44</td>
<td>164-36</td>
<td>Bl, Cg, Np</td>
</tr>
<tr>
<td>13 July 2013</td>
<td>70-37</td>
<td>161-33</td>
<td>Bl, Cg, Nf, Np, Ov</td>
</tr>
<tr>
<td>14 July 2013</td>
<td>70-06</td>
<td>164-54</td>
<td>Bl, Cg, Eu, Nc, Nf, Np, Tl, Ov</td>
</tr>
<tr>
<td>14 July 2013</td>
<td>70-24</td>
<td>163-30</td>
<td>Bl, Cg, Eu, Nf, Np, Ov</td>
</tr>
<tr>
<td>15 July 2013</td>
<td>68-31</td>
<td>168-32</td>
<td>Bl, Cg, Eb, Nc, Nf, Np, Ov</td>
</tr>
<tr>
<td>16 July 2013</td>
<td>67-38</td>
<td>168-57</td>
<td>Bl, Cg, Eb, Eu, Nc, Nf, Np, Tl, Ov</td>
</tr>
<tr>
<td>31 Aug. 2013</td>
<td>65-41</td>
<td>168-17</td>
<td>Ov</td>
</tr>
<tr>
<td>31 Aug. 2013</td>
<td>66-30</td>
<td>168-45</td>
<td>Ov</td>
</tr>
<tr>
<td>3 Sep. 2013</td>
<td>71-25</td>
<td>157-31</td>
<td>Ch, Eu, Ml</td>
</tr>
<tr>
<td>27 Sep. 2013</td>
<td>73-09</td>
<td>162-17</td>
<td>Ch, Ml</td>
</tr>
</tbody>
</table>

**Results**

**Hydrography**

The trap mooring depth was mainly stable between 180-190 m (mean: 184 m, first year) and 250-260 m (mean: 256 m, second year) but temporarily deepened to approximately 300 m in July 2012 (Fig. 2a). This change was thought to be caused by the temporal strong current velocity at that time (Onodera et al., 2015). Temperature at the sediment trap ranged from −1.56°C to −0.07°C, and rapid changes in temperature were reflected by the changes in the depth of the trap (Fig. 2a, 2b). The current velocity simulated by the ocean circulation model showed a slow current around the trap (< 2.7 cm s⁻¹ [mean 1.0 cm s⁻¹] at 188 m and < 1.2 cm s⁻¹ [mean 0.3 cm s⁻¹] at 275 m) (Fig. 2c). From two time CTD casts at the station, four water masses were identified at 0-500 m in the water column: i.e., the Surface Mixed Layer (SML, 0-25 m), Pacific Summer Water (PSW, 25-100 m), Pacific Winter Water (PWW, 100-250 m) and the Atlantic Water (AW, >250 m) (Fig. 2d, 2e) (McLaughlin et al., 2011). The water mass was PWW at 180-190 m depth in the first year, and AW was at 250-260 m depth in the second year.

The sea ice concentration around St. NAPt showed clear seasonal changes. Sea ice decreased from late July, melted completely from mid-August to early October, increased rapidly in mid-October and covered completely from November to June (Fig. 3a). High chl. a was observed during the open water period (August-September) (Fig. 3a). The total mass flux ranged from 0.1-215.9 mg DM m⁻² day⁻¹, showed large seasonality and peaked during November-December in both years (Fig. 3a). At St. NAPt, the daylight hours showed great seasonal changes: polar night occurred from mid-
November to early February, and the midnight Sun occurred from early May to mid-August (Fig. 3b).

**Fecal pellets**

For the fecal pellets collected by sediment trap, oval and spherical pellets were dominant and accounted for 60% and 30% of the annual mean number, respectively (Fig. 3c). The occurrence of brown-colored pellets showed clear seasonality and occurred only during July-August, reaching 80% of the fecal pellet number at that time. The fecal pellet length varied with each type: oval pellets were 0.07-0.88 mm (mean±SD = 0.26±0.12 mm), cylinder pellets were 0.25-1.20 mm (0.58±0.26 mm), spherical pellets were 0.04-0.26 mm (0.09±0.03 mm) and brown-colored pellets were 0.09-1.02 mm (0.25±0.08 mm) (Fig. 4). Seasonal changes in the pellet size were slightly observed, but were not significant (p > 0.05, Tukey-Kramer Test).

The shipboard experiments results showed that oval and cylinder pellets were egested by various species, brown-colored pellets were egested only by the amphipod *T. libellula*, and spherical pellets were not egested by any species (Fig. 5). Oval pellets were egested by appendicularians (*O. van-*)

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Fig. 2. Seasonal changes in depth (a) and temperature (b) monitored by the moored sediment trap at St. NAP during October 2010 to September 2012. Current velocity at 188 m and 275 m of St. NAP (c) estimated by a physical ocean general circulation model. Temperature (d) and salinity (e) observed from CTD casts at St. NAP on 30 October 2010 and 21 September 2012. Shades indicate the trap depths (180-190 m and 250-260 m). SML: Surface Mixed Layer (0-25 m), PSW: Pacific Summer Water (25-100 m), PWW: Pacific Winter Water (100-250 m) and AW: Atlantic Water (> 250 m).

Fig. 3. Seasonal changes in sea ice concentration, surface chl. *a* (from satellite) and total mass flux (a), daylight hours (b) and composition in number of four types of fecal pellets (c). Based on morphology, four types of fecal pellets were identified: oval (OVL), cylinder (CYL), spherical (SPR) and brown-colored (BRW) types.

Fig. 4. Seasonal changes in length of fecal pellets. Symbols and bars indicate means and standard deviations, respectively. OVL: oval, CYL: cylinder, SPR: spherical and BRW: brown-colored type. Example pictures are shown for each morphological type. Scale bars: 100 µm.
hoeffeni), copepods (M. longa) and barnacle larvae (Fig. 5). The cylinder pellets were egested by six copepods (C. glacialis C5, C. hyperboreus C6F, E. hungii C6F, N. cristatus C5, N. flemingeri C5 and N. plumchrus C5), euphausiids and decapod larvae. The fecal pellet length in the experiment was similar to or larger than those by the sediment trap (Fig. 5).

Zooplankton community

The zooplankton flux ranged from 35–739 ind. m$^{-2}$ day$^{-1}$ and was greater during October–November in both years (Fig. 6). For taxonomic composition, the poecilostomatoid copepods were dominant (69% of the annual mean flux) followed by calanoid copepods (17%) (Fig. 6). From the viewpoint of seasonality, barnacle and bivalve larvae were abundant during August–September 2011 and August–November of 2010 and 2011, respectively (Fig. 6). It was remarkable that both barnacle and bivalve larvae were absent during August–September in 2012.

Based on the zooplankton flux, the 56 zooplankton swimmers were largely classified into three groups (A–C) (Fig. 6). The occurrence of each group showed clear seasonality. For both years, group A was observed from September to February and group B occurred from March to July (Fig. 6). Group C was observed in August 2011, but was not seen in 2012.

From the SIMPER analysis, the dominant poecilostomatoid copepod Oncaea parila contributed to separate groups A–C and B–C (Table 2). For calanoid copepods, C. hyperboreus, Paraeuchaeta glacialis, Heterorhabdus norvegicus, M. longa and Scaphocalanus brevicornis were identified to characterize each group. Bivalve larvae characterized separating groups A–B and A–C, and barnacle larvae separated groups A–C and B–C (Table 2).

For the abundance of each taxon, calanoid copepods, poecilostomatoid copepods, total copepods, barnacle larvae, bivalve larvae and total zooplankton were significantly varied between groups (Table 3). Group A was characterized by the dominance of total zooplankton, total copepods, poecilostomatoid copepods and bivalve larvae, and group C was characterized by the dominance of amphipods and barnacle larvae.

Discussion

Fecal pellets

Zooplankton fecal pellets have roles in the acceleration of the vertical material flux to the deep-sea and as food resources for detritivorous zooplankton (Taguchi and Saino, 1998; Turner, 2002). Fecal pellets were also thought to be food resources for copepods and appendicularians in the Arctic Ocean (Sampei et al., 2009b). Especially, small poecilostomatoid copepods are known to attach on fecal pellets for grazing (coprophagy) (Steinberg et al., 1998), which results in the comminution (coprorhexy) of the fecal pellets (Poulsen and Kiorboe, 2005). In this study, the detritivorous copepods (Oncaea spp.) numerically dominated (Fig. 6). This fact suggested that the fecal pellets collected by the
sediment trap in this study were affected by coprophagy and coprorhexy of *Oncaea* spp.

Morphology (size, shape and color) of fecal pellets varies with the egested taxa/species and their food components (Riser et al., 2002; Wilson et al., 2008). In this study, fecal pellets were separated into four types, and oval and spherical pellets were numerically dominant throughout the year (Fig. 3c). From the ship-board experiments, the oval pellets were egested by appendicularians (*O. vanhoeffeni*), copepod *M. longa* and barnacle larvae (Fig. 5). Many individuals of *M. longa* were collected by the sediment trap (Matsuno et al., 2014, 2015).

*Metridia longa* are known to have no diapause phase in the Arctic Ocean and continue grazing throughout the year (Båmstedt and Ervik, 1984; Grønvik and Hopkins, 1984). These facts suggested that the oval fecal pellets egested by *M. longa* may have been included in the sediment trap samples. *Oikopleura vanhoeffeni* also occurs during July–September and actively grazes on the ice-edge bloom (Acuña et al., 1999). From the egestion experiments, the fecal pellet length egested by *O. vanhoeffeni* was large, especially that in July, which was larger than in September (Fig. 5). This result was due to the differences in the body length of the specimens used for the experiments between the sampling dates (trunk length was 3.3 mm in July versus 0.5 mm in September). Thus, oval pellets in the sediment trap may have been egested by *M. longa* and *O. vanhoeffeni*.

While the composition of the cylinder pellets was low in the sediment trap samples (Fig. 3c), various species (six copepods, euphausiids and decapod larvae) egested cylinder pellets in the ship-board experiments (Fig. 5). The morphology of fecal pellets is known to vary with taxa; copepods egest cylinder pellets, euphausiids egest cylinder or filiform pellets and appendicularians egest oval pellets (Riser et al., 2002; Wilson et al., 2008). The results of this study (copepods, euphausiids and decapod larvae egested cylinder pellets) corresponded with the previous study. While the fecal pellet length of the cylinder pellet showed large seasonal fluctuations, a significant seasonal pattern was not detected (Fig. 4). These results were caused by the mixture of the cylinder pellets, which were egested by various taxa/species.

**Table 2.** Ranking of taxa according to their relative contribution (%) to the multivariate similarities between pairs of the mesozooplankton groups (A-C) identified by the cluster analysis for mesozooplankton community collected by the sediment trap at St. NAPt in the western Arctic Ocean from October 2010 to September 2012 (cf. Fig. 6).

<table>
<thead>
<tr>
<th>Group</th>
<th>A (%)</th>
<th>B (%)</th>
<th>C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Bivalve larvae (12%)</td>
<td>Limacina helicina (7%)</td>
<td>Scaphocalanus brevicornis (5%)</td>
</tr>
<tr>
<td>C</td>
<td><em>Oncaea parila</em> (12%)</td>
<td>Barnacle larvae (12%)</td>
<td><em>Oncaea parila</em> (10%)</td>
</tr>
</tbody>
</table>

**Table 3.** Dominant mesozooplankton fluxes collected by the sediment trap at St. NAPt in the western Arctic Ocean from October 2010 to September 2012. Values are means and standard deviations of the three groups identified by Bray-Curtis dissimilarity (cf. Fig. 6). Differences between groups were tested by a one-way ANOVA and Tukey-Kramer test. Any groups not connected by the underlines were significantly different (p<0.05). Numbers in the parentheses indicate the number of samples included for each group. *: p<0.05, **: p<0.01, ***: p<0.001, NS: not significant.

<table>
<thead>
<tr>
<th>Species/Taxa</th>
<th>Flux (ind. m⁻² day⁻¹)</th>
<th>one-way ANOVA</th>
<th>Tukey-Kramer Test</th>
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<tbody>
<tr>
<td></td>
<td>A (21)</td>
<td>B (28)</td>
<td>C (3)</td>
</tr>
<tr>
<td>Copepods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calanoid copepods</td>
<td>19.4±8.5</td>
<td>27.6±14.0</td>
<td>15.4±2.7</td>
</tr>
<tr>
<td>Cyclopoid copepods</td>
<td>0.6±1.0</td>
<td>0.7±1.0</td>
<td>0</td>
</tr>
<tr>
<td>Plocistomatoid copepods</td>
<td>175.4±93.1</td>
<td>119.2±83.0</td>
<td>11.8±7.0</td>
</tr>
<tr>
<td>Total copepods</td>
<td>195.4±98.1</td>
<td>147.4±92.7</td>
<td>27.4±4.3</td>
</tr>
<tr>
<td>Amphipods</td>
<td>0.8±0.8</td>
<td>3.3±13.4</td>
<td>2.1±1.8</td>
</tr>
<tr>
<td>Barnacle larvae</td>
<td>2.0±5.0</td>
<td>0.1±0.4</td>
<td>11.4±7.7</td>
</tr>
<tr>
<td>Bivalve larvae</td>
<td>61.8±113.2</td>
<td>1.2±4.4</td>
<td>3.5±3.9</td>
</tr>
<tr>
<td>Total zooplankton</td>
<td>270.7±203.1</td>
<td>158.4±92.5</td>
<td>49.0±11.8</td>
</tr>
</tbody>
</table>
ship-board experiments (Fig. 5). Small spherical pellets (<100 µm) are known to be egested by copepod nauplii and microzooplankton (e.g., radiolarians) (Gowing and Silver, 1985; Gowing et al., 2001; Turner, 2002). Because the mean length of the spherical pellets in this study was 90 µm, they might be egested by copepod nauplii and microzooplankton. An alternative explanation is that the large-sized other morphotype fecal pellets might be broken into small spherical pellets through the decomposition by bacteria (Ploug et al., 1999; Goldthwait et al., 2005) and coprophagy or coprorhexy by poecilostomatoid copepods (Smetacek, 1980; Lampitt et al., 1990) during the course of sinking.

Brown-colored pellets occurred during a limited season (July–August) (Fig. 3c), and only the amphipod T. libellula egested the brown-colored pellets during the ship-board experiments (Fig. 5). Macro-sized amphipods can feed on various food, from small copepods to marine snow (Lampitt et al., 1990) during the course of sinking. Thus, they egested yellow–green colored pellets during ice-algae feeding, while they egested brown-colored pellets during carnivorous feeding (Werner, 2000). These facts suggested that the brown-colored pellets collected by the sediment trap in this study may have been egested by carnivorous amphipods. The seasonal restricted peak of brown-colored pellets (July–August) would be a reflection of the high grazing activity of amphipods in the upper layer during that time. Because this period corresponded with the timing of amphipods in the upper layer during that period, their absence during summer 2012 suggested that inter-annual changes in the current flow in the upper layer of St. NAPt may have occurred, i.e., weakened current from the shelf in summer 2012. Because the sediment trap samples of this study, inter-annual changes in the total mass flux and the diatom community were reported (Onodera et al., 2015). They showed that the total mass flux during summer 2012 was lower than that in summer 2011 (cf. Fig. 3a), and the ice-algae Fossula arctica dominated in the diatom community during summer 2011, while it was absent in summer 2012 (Onodera et al., 2015). Because the eddy included high amounts of particles and zooplankton and was transported westward by the Beaufort Gyre, the presence of the eddy increased the vertical material flux at St. NAPt during autumn (Watanabe et al., 2014).

Based on the same trap samples of this study, inter-annual changes in the total mass flux and the diatom community were reported (Onodera et al., 2015). They showed that the total mass flux during summer 2012 was lower than that in summer 2011 (cf. Fig. 3a), and the ice-algae Fossula arctica dominated in the diatom community during summer 2011, while it was absent in summer 2012 (Onodera et al., 2015). Because the bottom depth was deep (ca. 1,900 m) at St. NAPt, the larvae released by sympatric benthic adults may not be the case in this study. Barnacle (Balanus crenatus) adults release their larvae during phytoplankton blooms (Crisp, 1962; Clare and Walker, 1986), and the larvae spend two to three weeks in the water column before settling to the sea bottom (Herz, 1933). Bivalves are also known to release their larvae during the two months after a phytoplankton bloom (Lammens, 1967). The released larvae will be transported to the shelf during that period, and the phytoplankton bloom to post-bloom might be transported to St. NAPt. Therefore, the current forcing horizontal transport of various zooplankton from Chukchi Sea shelf to the basin has well known (Ashjian et al., 2005). The later occurrence period of barnacle and bivalve larvae (August–November) than the open water bloom (August–September) may be a reflection of the northern transport of larvae to St. NAPt in this study.

Seasonal change was also the case for holoplankton (Fig. 6). Seasonal changes in this zooplankton group were governed by various calanoid copepods (Table 2). For calanoid copepods at St. NAPt, C. hyperboreus, H. norvegicus, M. longa and P. glacialis were dominant, and seasonal changes in the diatom community were related to their vertical migration behavior (in terms of diel, seasonal and ontogenetic sense) (Matsuno et al., 2014, 2015). Thus, seasonal changes in the zooplankton community in this study were determined by two factors: 1) the occurrences of meroplanktonic larvae transported from shelf region and 2) seasonal changes in the vertical migration intensity of holoplanktonic calanoid copepods.

For the inter-annual changes in the zooplankton community, barnacle and bivalve larvae were abundant during August–September 2011, while they were both absent during August–September 2012 (Fig. 6). Because these larvae may be transported from the shelf region, their absence during summer 2012 suggested that inter-annual changes in the current flow in the upper layer of St. NAPt may have occurred, i.e., weakened current from the shelf in summer 2012. For the water current around St. NAPt, the northward current dominated throughout the year (Fig. 1), and a meso-scale eddy (diameter is 60–70 km) frequently occurred off of Barrow during the open water season (Kawaguchi et al., 2012; Watanabe et al., 2014). Because the eddy included high amounts of particles and zooplankton and was transported westward by the Beaufort Gyre, the presence of the eddy increased the vertical material flux at St. NAPt during autumn (Watanabe et al., 2014).
larvae, during summer 2012 (Onodera et al., 2015; Watanabe et al., 2015).

Conclusion

Through this study, the following two points were evidence of the biological application of the sediment trap samples. First, the water mass formation in the upper layer can alter transport the zooplankton flux to a deep layer. Second, the feeding intensity of the surface zooplankton community can affect the vertical flux of fecal pellets to the deep-sea in the Arctic Ocean.

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