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Comparisons between POC and zooplankton swimmer flux from sediment traps in the subarctic and subtropical North Pacific

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ABSTRACT

Seasonal changes in zooplankton swimmer (ZS) abundance, biomass and community structure were evaluated based on samples collected by moored sediment traps at a depth of 200 m in the subarctic (SA) and subtropical (ST) western North Pacific. Based on these samples, we made comparisons on two topics: 1) latitudinal (subarctic vs. subtropical) changes in ZS abundance, biomass and community and 2) quantitative differences between the ZS and particle organic carbon (POC) fluxes based on data from moored or drifting sediment traps. The results showed that the ZS flux was greater in the SA (annual mean: 311 ind. m^{-2} day^{-1} or 258 mg C m^{-2} day^{-1}) than in the ST (135 ind. m^{-2} day^{-1} or 38 mg C m^{-2} day^{-1}). The peak ZS flux was observed from July–August in the SA and from April–May in the ST. The dominant taxa were Copepoda and Chaetognatha in the SA and Ostracoda and Mollusca in the ST. These latitudinal differences are likely related to the dominance of large-sized Copepoda in the SA, regional differences in the timing of the spring phytoplankton bloom, and the magnitude and size structure of primary producers. The percent composition of ZS to the total C flux (= ZS + POC flux) varied by region: 85–95% in the SA and 47–75% in the ST. These differences between the ZS composition and the total C flux are most likely caused by the dominance of large-sized Copepoda (*Neocalanus* spp. and *Eucalanus bungii*) in the SA.

1. Introduction

A sediment trap is an oceanographic observation device that is moored at a certain depth in the water column and used to collect sinking particles. Since the 1970s, various studies have been conducted on sinking particles using sediment traps. For example, the relationships between particle organic carbon (POC) flux and primary production (Silver and Gowing, 1991) as well as the major components of POC flux (biogenic opal and $CaCO_3$) have been studied (Honda et al., 2016). Regarding these topics, various aspects of sinking POC flux have been reported in different oceans (cf. Lohrenz et al., 1992; Buesseler et al., 2000, 2007). Most studies using sediment traps collected zooplankton, called "swimmers", in their samples, and these were not treated as sinking particles; therefore, the swimmers were removed from the POC flux measurements (Knauer et al., 1979; Silver and Gowing, 1991). Sometimes, it is estimated that the contribution of the swimmers and larvacean houses could be as much as 96% of the measured carbon flux, quantified by sediment traps at shallower depths in the upper few 100 m (Michaels et al., 1990).

Several more recent studies, however, have focused on zooplankton swimmers (ZS). For example, the flux caused by Copepoda carcasses is reported to be greater than their fecal pellets in oligotrophic oceans (Frangoulis et al., 2011). In the Arctic region, seasonal changes in the population structure of Mollusca *Limacina helicina* and Copepoda *Metridia longa* can be evaluated by the data collected through sediment traps (Makabe et al., 2016). Considering the results from these previous studies, the usefulness of sediment traps for plankton ecological studies has been reconsidered. For studying ZS, sediment traps have the advantage of being able to collect high-resolution time-series samples in regions where access is difficult (e.g., oceanic regions or ice-covered oceans). Recently, seasonal changes in zooplankton communities and the life cycles of dominant zooplankton species in oceanic or ice-covered oceans have been evaluated based on analyses of ZS samples collected using sediment traps (Ota et al., 2008; Ohashi et al., 2011; Matsuno et al., 2014, 2015). Although zooplankton swimmers have been studied based on data collected from sediment traps, several problems remain unsolved. Thus, little information is available for regional patterns in ZS (subarctic vs. subtropical) and for quantitative comparisons between sinking POC flux and ZS flux (Buesseler et al., 2007).

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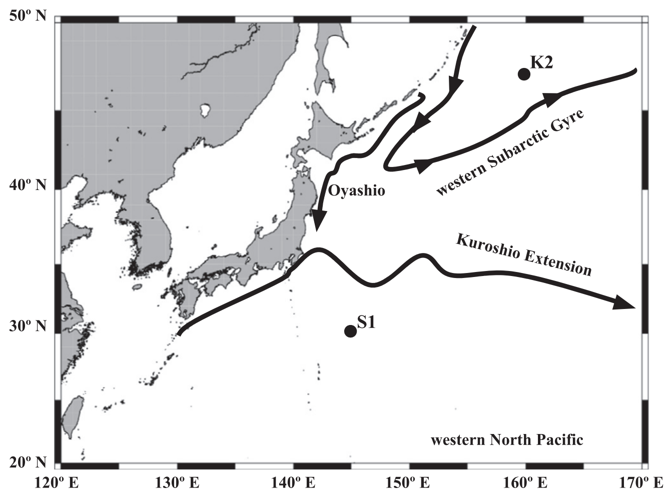

Fig. 1. Location of sampling stations: K2 is in the subarctic and S1 is in the subtropical western North Pacific. The approximate directions of current flows are shown with arrows (cf. Yasuda, 2003).

Table 1
Sampler rotation timings of moored sediment traps (MSTs) and deployed timings of drifting sediment traps (DSTs) at the St. K2 (47°N, 160°E) in the subarctic and the St. S1 (30°N, 145°E) in the subtropical western North Pacific. Dates were arranged according to the order of the Julian day. Parentheses indicates deployed durations (days) for DSTs.

K2		S1	
MST	DST	MST	DST
25 July 2013	1 July 2011 (5.0)	18 July 2013	25 July 2011 (4.3)
1 Aug. 2013		5 Aug. 2013	
8 Aug. 2013		23 Aug. 2013	
15 Aug. 2013		10 Sep. 2013	
22 Aug. 2013		28 Sep. 2013	
5 Sep. 2013		16 Oct. 2013	
19 Sep. 2013		3 Nov. 2013	8 Nov. 2010 (3.1)
3 Oct. 2013		21 Nov. 2013	
17 Oct. 2013		9 Dec. 2013	
31 Oct. 2013	28 Oct. 2010 (3.0)	27 Dec. 2013	
14 Nov. 2013		14 Jan. 2014	
28 Nov. 2013		23 Jan. 2014	30 Jan. 2010 (3.0)
12 Dec. 2013		1 Feb. 2014	
26 Dec. 2013		10 Feb. 2014	
9 Jan. 2014		19 Feb. 2014	15 Feb. 2011 (3.0)
23 Jan. 2014	23 Jan. 2010 (1.9)	28 Feb. 2014	
6 Feb. 2014		9 Mar. 2014	
20 Feb. 2014	25 Feb. 2011 (4.0)	18 Mar. 2014	
6 Mar. 2014		27 Mar. 2014	
20 Mar. 2014		5 Apr. 2014	
3 Apr. 2014		23 Apr. 2014	28 Apr. 2011 (3.1)
10 Apr. 2014	19 Apr. 2011 (3.0)	11 May 2014	
17 Apr. 2014		29 May 2014	
24 Apr. 2014		16 June 2014	
1 May 2014		4 July 2014	28 June 2012 (3.0)
8 May 2014	11 June 2012 (3.0)		

In this study, we evaluated seasonal changes in ZS abundance, biomass and community structure based on samples collected by moored sediment traps at 200 m (the bottom of the epipelagic zone) in the subarctic and subtropical western North Pacific. These data were compared with the POC flux, which was quantified based on data collected from moored and drifting sediment traps (Honda et al., 2016). Regarding these comparisons, we focus on the following two topics: 1) latitudinal (subarctic vs. subtropical) changes in ZS abundance, biomass and community and 2) quantitative differences between the ZS and POC fluxes based on data collected by moored or drifting sediment traps.

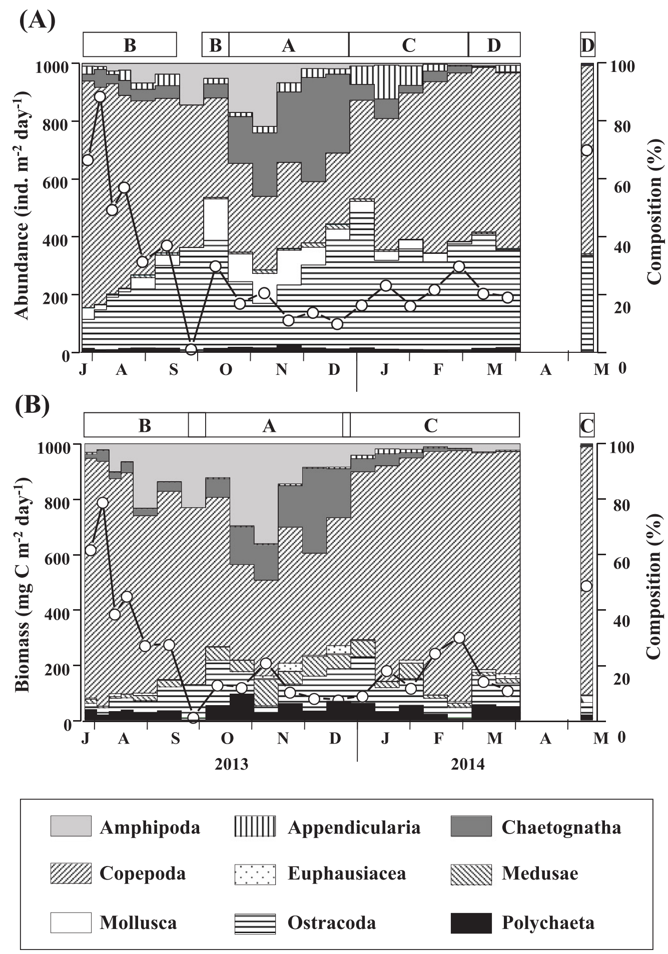

Fig. 2. Zooplankton swimmer abundance (A) and biomass (B) collected at 200 m of the St. K2 in the western subarctic Pacific from July 25, 2013 to May 8, 2014. The line with an open circle indicates the total zooplankton swimmer abundance or biomass, and the fills indicate the percentage composition of the different taxa. Note that the samples were unavailable from April 3 to May 1, 2014. Based on cluster analyses, the samples were separated into four (A–D, abundance) or three (A–C, biomass) groups (cf. Fig. 3).

2. Materials and methods

2.1. Field sampling

Samples were collected using time-series sediment traps (SMD26S-26 with 26 collecting cups, conical-shaped, and an open mouth area of 0.5 m^2; Nichiyu Giken Kogyo Co., Ltd., Kawagoe, Japan) moored at a depth of 200 m in the subarctic station K2 (47°00′ N, 160°00′E, bottom depth: 5200 m) and subtropical station S1 (30°00′ N, 145°00′E, bottom depth: 5700 m) of the western North Pacific from July 25, 2013 to May 15, 2014 (St. K2) and July 18, 2013 to July 4, 2014 (St. S1), respectively (Fig. 1, Table 1). The traps were anchored with rope to the sea bottom at each station. Within the trap cup, 10% buffered formalin seawater was added before deployment. After the traps were recovered, the samples were gently sieved with a 1 mm mesh. We treated all samples < 1 mm as POC and samples > 1 mm as ZS. It should be noted that the 1 mm mesh size would certainly allow smaller swimmers (e.g., young stages of copepods) to pass through the mesh into the POC fraction. While it is a source of error, microscopic observation confirmed that the volume of swimmers was a minor component of the < 1 mm fraction (data not shown).

2.2. Sample treatment

ZS samples were sorted for taxa and counted using a

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