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 versus 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. 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. Percent compositions of ZS to the total C flux (= ZS+POC flux) varied with 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.

Keywords: Sediment trap, Swimmer, Copepoda, Active carbon flux

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 trap 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

45 their fecal pellets in oligotrophic oceans (Frangoulis et al., 2011). In the Arctic region,
46 seasonal changes in the population structure of Mollusca *Limacina helicina* and
47 Copepoda *Metridia longa* can be evaluated by data collected through sediment traps
48 (Makabe et al., 2016). Considering the results from these previous studies, the
49 usefulness of sediment traps for plankton ecological studies has been reconsidered. For
50 studying ZS, sediment traps have the advantage of being able to collect high-resolution
51 time-series samples in regions where access is difficult (e.g., oceanic regions or ice-
52 covered oceans). Recently, seasonal changes in zooplankton communities and life
53 cycles of dominant zooplankton species at oceanic or ice-covered oceans have been
54 evaluated based on analyses of ZS samples collected using sediment traps (Ota et al.,
55 2008; Ohashi et al., 2011; Matsuno et al., 2014, 2015). Although zooplankton
56 swimmers have been studied based on data collected from sediment traps, several
57 problems remain unsolved. Thus, little information is available for regional patterns in
58 ZS (subarctic vs. subtropical) and for quantitative comparisons between sinking POC flux
59 and ZS flux (Buesseler et al., 2007).

60 In this study, we evaluated seasonal changes in ZS abundance, biomass and
61 community structure based on samples collected by moored sediment traps at 200 m

(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.

2. Materials and Methods

2.1. Field sampling

Samples were collected using time-series sediment traps (SMD26S-26 with 26 collecting cups, conical shape, and an open mouth area of 0.5 m^2, Nichiyu Giken Kogyo Co. Ltd.) 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 25 July 2013 to 15 May 2014 (St. K2) and 18 July 2013 to 4 July 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

78 seawater was added before deployment. After the traps were recovered, the samples
79 were gently sieved with a 1 mm mesh. We treated all samples <1 mm as POC and
80 samples >1 mm as ZS. It should be noted that the 1mm mesh size would certainly allow
81 smaller swimmers (e.g., young stages of copepods) to pass through the mesh into the POC
82 fraction. While it is a source of error, microscopic observation confirmed that the
83 volume of swimmer was minor component on <1 mm fraction (data not shown).

84 *2.2. Sample treatment*

85 ZS samples were sorted for taxa and counted using a stereomicroscope; then, the
86 wet mass (WM) was weighed with a precision of 0.1 mg by an electric balance (AE100,
87 Mettler-Toledo International Inc.). WM data were converted to dry mass (DM) using
88 water contents (WC) that varied by taxa (80% for Amphipoda, Copepoda, Euphausiacea,
89 Mollusca, Ostracoda and Polychaeta; 90% for Chaetognatha; and 96% for Appendicularia
90 and Medusae) (DM=WM×[1-WC×0.01]) (Postel et al., 2000). Finally, DM data were
91 converted to carbon mass using carbon contents that varied by taxa (Amphipoda:
92 37.2%DM, Appendicularia: 56.4%DM, Chaetognatha: 10.9%DM, Copepoda: 52.8%DM,
93 Euphausiacea: 43.0%DM, Medusae: 7.2%DM, Mollusca: 25.0%DM, Ostracoda:

42.5%DM and Polychaeta: 29.9%DM) (Kitamura et al., 2016).

The zooplankton swimmer abundance (ZSA, ind. m^{-2} day^{-1}) and biomass (ZSB, mg C m^{-2} day^{-1}) were calculated using the following equations:

$$ZSA = A / 0.5 / D \quad (1)$$

$$ZSB = B / 0.5 / D \quad (2)$$

where A is abundance (ind. $sample^{-1}$) and B is biomass (mg C $sample^{-1}$) per sample, 0.5 is the mouth area (m^2) of the sediment trap and D is the rotation interval of the trap sample (day). The rotation interval was 7–14 days at St. K2 and 9–18 days at St. S1 (Table 1).

For the POC flux collected by moored sediment traps (MSTs), samples with <1 mm were filtered through a GF/F filter and dried. Elemental analyses (2400 CHN/O, PerkinElmer, Inc.) were made on the dried samples, and the results on organic carbon were expressed as the POC flux (mg C m^{-2} day^{-1}).

For the POC flux collected by drifting sediment traps (DSTs), traditional, surface-tethered particle interceptor traps (PITs) (Knauer et al. 1979) constructed of eight cylinders with a collection area and an aspect ratio of 0.0038 m^2 and 8.27 (620 mm length/75 mm width), respectively, were deployed for several days at six occasions at

each station (Table 1).

Detailed methods for MSTs and DSTs were presented in Honda et al. (2016). Data on the POC flux using MSTs and DSTs were sourced from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) database, which has data collected from the K2 and S1 time-series stations (netCDF format for OceanSITES; https://ebcrpa.jamstec.go.jp/k2s1/en/index.html).

2.3. Statistical analysis

To evaluate seasonal changes in ZS, ZSA and ZSB data were log transformed (log [ZSA+1] or log [ZSB+1]) prior to analyses to reduce their variability bias. After that, similarities between samples were identified using the Bray-Curtis method (Bray-Curtis, 1957). To group the samples, 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). We evaluated the differences in the ZSA and the ZSB of each taxa between groups using one-way ANOVA.

To evaluate regional differences in ZS, ZSA and ZSB data and their taxonomic

125 composition were compared between the subarctic (K2) and subtropical (S1) regions
126 using a *U*-test.

127 For quantitative comparison between the ZS and POC fluxes, we calculated the
128 total C flux (= ZSB+POC flux) and the percentage composition of the ZSB in the total C
129 flux. All statistical analyses were made using PRIMER v7 (PRIMER-E Ltd.) and Stat
130 View v5.0.

131 **3. Results**

132 *3.1. Subarctic region (K2)*

133 At the subarctic K2, the ZSA ranged from 11.9 to 887.6 ind. m^{-2} day^{-1}, and the
134 annual mean was 310.7±48.5 ind. m^{-2} day^{-1} (mean±SD) (Fig. 2A). The dominant taxa
135 in the ZSA was Copepoda (50±4%), followed by Ostracoda (28±2%) and Chaetognatha
136 (9±2%). The cluster analysis results classified the ZSA samples into four groups (A–D)
137 (Fig. 3A). A comparison between the groups showed that four taxa (Chaetognatha,
138 Copepoda, Ostracoda and Polychaeta) had significant inter-group differences in the ZSA
139 (one-way ANOVA, $p < 0.05$). Temporally, group B, which is characterized by a high

140 ZSA dominated by Copepoda, was observed from late July to mid-October 2013 (Fig.
141 2A). Group A, with a low ZSA that was dominated by Chaetognatha, was found from
142 mid-October to late December 2013 (Fig. 2A).

143 The ZSB in K2 ranged from 11.3 to 787.9 mg C m^{-2} day^{-1} with a mean of
144 258.3±44.1 mg C m^{-2} day^{-1} (mean±SD) (Fig. 2B). The dominant taxa in the ZSB were
145 Copepoda (68±4%), followed by Amphipoda (9±2%) and Chaetognatha (6±2%). The
146 results from a cluster analysis classified ZSB samples into three groups (A–C) (Fig. 3B).
147 Comparisons between groups indicate that five taxa (Amphipoda, Chaetognatha,
148 Copepoda, Ostracoda and Polychaeta) had significantly different ZSBs (one-way
149 ANOVA, $p < 0.05$). From late July to mid-October 2013, group B was observed and
150 was characterized by a high ZSB dominated by Copepoda (mean composition in the ZSB
151 for group B accounted for 78%). From mid-October to late December, group A was
152 observed and had a low ZSB that was dominated by Chaetognatha (Fig. 2B).

153 *3.2. Subtropical region (S1)*

154 At the subtropical S1, the ZSA ranged from 40.4 to 372.7 ind. m^{-2} day^{-1} with a
155 mean of 134.9±18.3 ind. m^{-2} day^{-1} (mean±SD) (Fig. 4A). The dominant taxa in the ZSA

156 were Ostracoda (48±3%), followed by Mollusca (26±3%) and Copepoda (9±1%). The
157 results from a cluster analysis classified ZSA samples into four groups (A–D) (Fig. 5A).
158 Comparisons between groups showed that there were six taxa (Amphipoda, Copepoda,
159 Euphausiacea, Medusa, Mollusca and Ostracoda) that had significantly different ZSAs
160 (one-way ANOVA, $p < 0.05$). Temporally, group A, which was characterized by a high
161 ZSA for all taxa, was observed from early March to May 2013 (Fig. 5A).

162 The ZSB in S1 ranged from 13.4 to 133.5 mg C m^{-2} day^{-1}, and its mean was
163 37.8±5.9 mg C m^{-2} day^{-1} (mean±SD) (Fig. 4B). Dominant taxa in the ZSB were
164 Mollusca (29±3%), followed by Amphipoda (18±2%) and Copepoda (18±1%). The
165 results from a cluster analysis classified ZSB samples into four groups (A–C) (Fig. 5B).
166 Comparisons between groups showed that there were six taxa (Amphipoda, Chaetognatha,
167 Copepoda, Medusa, Mollusca and Ostracoda) with a significantly different ZSB (one-
168 way ANOVA, $p < 0.05$). Temporally, group A, which had a high ZSB for all taxa, was
169 observed from March to May 2013 (Fig. 5B).

170 *3.3. Comparison between K2 and S1*

171 Regional comparisons (K2 vs S1) in the ZSA and the ZSB yielded significant

172 regional differences for several taxa (Table 2). Common patterns in the ZSA and the
173 ZSB were observed for Chaetognatha and Copepoda. Thus, both taxa had significantly
174 greater values in the subarctic K2 (Table 2).

175 Regional differences in taxonomic composition were also detected for seven taxa
176 in both the ZSA and the ZSB (*U*-test, $p<0.05$, Fig. 6). For both the ZSA and the ZSB,
177 Copepoda (K2: 50–68%, S1: 9–18%) and Chaetognatha (K2: 6–9%, S1: 0–1%) had
178 significantly higher percentage compositions among all taxa found in the subarctic region
179 (Fig. 6). In contrast, Euphausiacea (K2: 0–1%, S1: 3–11%), Medusa (K2: 0–1%, S1: 3–
180 6%), Mollusca (K2: 3–4%, S1: 26–29%) and Ostracoda (K2: 8–28%, S1: 16–48%) had
181 significantly higher percentage compositions among all taxa observed in the subtropical
182 region (Fig. 6).

183 *3.4. Comparison between the POC flux and ZS*

184 From POC flux data at each station (Honda et al., 2016), the total C flux (= POC
185 flux + ZSB) was calculated. At K2, the annual mean POC flux collected using MSTs
186 was 15.0 mg C m^{-2} day^{-1} (Table 3). Since the annual mean ZSB was 258.3±44.1 mg C
187 m^{-2} day^{-1} at K2, the ZSB was higher than the POC flux throughout the year; the ZSB

188 accounted for 94.5% of the total C flux. At the same station, the POC flux collected
189 using DSTs was 45.2 mg C m^{-2} day^{-1}, and the ZSB accounted for 85.1% of the total C
190 when the POC flux was evaluated using DSTs.

191 At S1, the annual mean POC flux collected by moored sediment traps was 12.5
192 mg C m^{-2} day^{-1} (Table 3). The annual mean of ZSB at the same station was 37.8±5.9
193 mg C m^{-2} day^{-1}; the ZSB accounted for 75.1% in the total C flux. The annual mean POC
194 flux collected using DSTs at the same station was 42.1 mg C m^{-2} day^{-1}; thus, the percent
195 composition of the ZSB of total C was 47.3% when the POC flux was evaluated using
196 DSTs.

197 **4. Discussion**

198 *4.1. Comparison between subarctic and subtropical regions*

199 In this study, regional ZS differences between the subarctic K2 and the
200 subtropical S1 were observed in three ways. First, both the ZSA and the ZSB at K2 were
201 higher than those at S1. At K2, the ZSA (ind. m^{-2} day^{-1}) was 2.3 times higher (=
202 310.7/134.9), and the ZSB (mg C m^{-2} day^{-1}) was 6.5 times (= 246.0/37.8) higher than

those at S1 (Figs. 2, 4). Second, the seasonal peak timings of the ZSA and the ZSB varied by region; July–August for K2, and April–May for S1 (Figs. 2, 4). Third, the taxonomic composition varied by region; Copepoda and Chaetognatha dominated at K2, while Ostracoda and Mollusca dominated at S1 (Fig. 6). We discuss each of these three major differences below.

Regional differences in the ZSA and the ZSB can likely be explained by regional differences in the pelagic zooplankton community. Zooplankton biomasses at 0–200 m and 0–1000 m depths are higher at the subarctic K2 throughout the year by a factor of 8.5 to 14.0 times than at S1 (Kitamura et al., 2016). Regional differences in the zooplankton biomass between the subarctic and subtropical regions correspond well to the ZS differences observed in this study. For regional differences in hydrography, sea surface temperature was higher, and chlorophyll *a* (Chl. *a*) was lower for the subtropical region than the subarctic region (Longhurst, 2006; Honda et al., 2016; Kitamura et al., 2016). For the zooplankton biomass, the composition of herbivores varied by region: 80% for the subarctic region and as low as 30% for the subtropical region (Taniguchi, 1973). Latitudinal differences for the zooplankton community would be caused by the occurrence of large-bodied Copepoda in the subarctic region (Yamaguchi et al., 2004;

220 Steinberg et al., 2008).

221 Regarding seasonal changes, regional differences in the timing of the
222 phytoplankton bloom should be considered. The phytoplankton bloom period varies
223 between K2 and S1: June for K2 and March for S1 (Fujiki et al., 2014; Siswanto et al.,
224 2015). The factors controlling initiation of the phytoplankton bloom vary by region:
225 iron supplied through atmospheric dust is important in the subarctic region, while
226 nutrients supplied to the surface layer from vertical water mixing are more important for
227 the subtropical region (Longhurst, 2006; Fujiki et al., 2014, 2016). Compared with the
228 timing of those phytoplankton blooms, both the ZSA and the ZSB at K2 and S1 peaked
229 1–2 months after the phytoplankton blooms at each region (July–August at K2, April–
230 May at S1) (Figs. 2, 4). Thus, the seasonal timing of the primary production may affect
231 the temporal patterns of the ZSA and the ZSB for both regions.

232 Regarding taxonomic composition, the occurrence of large-sized Copepoda,
233 which undergo seasonal vertical migration from the surface to the deep layers, is highly
234 important. Copepoda dominate the ZSB in the subarctic region throughout the year
235 (68% in annual mean, Fig. 2B), in particular, large-sized Copepoda, including *Eucalanus*
236 *bungii*, *Neocalanus cristatus*, *N. flemingeri* and *N. plumchrus* (77% ZSA and 84% ZSB

237 of the total Copepoda observed, Table 4). These species have long generation lengths
238 (more than a year), spend diapause at deep layers, and perform seasonal ontogenetic
239 vertical migrations (Miller et al., 1984; Kobari et al., 2003). The seasonal timings of
240 their downward migrations from surface to deep layers correspond with the peak timings
241 of the ZSA and the ZSB (July–August) in the subarctic K2. In winter, these Copepoda
242 undergo diapause in the deep layers; therefore, their composition in the ZSA and the ZSB
243 may be low (Fig. 2).

244 In the subtropical region, these large-sized Copepoda do not occur (Taniguchi,
245 1973; Yamaguchi et al., 2004; Steinberg et al., 2008). Because of regional differences
246 in zooplankton fauna, the percentage composition of Copepoda in the ZSA and the ZSB
247 are relatively low in the subtropical region; alternatively, the percentage compositions of
248 Ostracoda and Mollusca are high (Fig. 4). In the subtropical region, Chl. *a* is low and is
249 mainly composed of pico-sized phytoplankton, such as the *Prochlorococcus* and
250 *Synechococcus* spp. (Longhurst, 2006). Most of the picophytoplankton are consumed
251 by small protozooplankton, such as flagellates, and they are fed by ciliates; thus, most of
252 the energy flow may enter the microbial loop in the subtropical region (Longhurst, 2006;
253 Fujiki et al., 2016). Most of the Mollusca in this study were shelled Gastropoda (N.

254 Yokoi, unpublished data). The feeding mechanism of shelled Gastropoda is to collect
255 food particles using a mucoid net (Gilmer and Harbison, 1986). Because the body size
256 of Ostracoda is relatively small, they can feed effectively on small particles. These
257 feeding mechanisms of Mollusca and Ostracoda may allow them to dominate the ZS
258 community at the subtropical S1 (Fig. 4).

259 *4.2. Comparison between the POC flux and ZS*

260 Concerning the POC flux, the MSTs collected less than the DSTs for both
261 locations (Table 3). From measurements of ^{230}Th, ^{231}Pa and the Th/Pa ratio, the trapping
262 efficiency of the MSTs in shallower waters (<1200 m depth) is low (Yu et al., 2001). At
263 shallower depths (150–200 m) in the Southern Ocean, the DSTs collected a higher POC
264 flux than the MSTs by a factor of 6.6 to 20 times (Sweeney et al., 2000; Buesseler et al.,
265 2010). Flow fields in cylindrical and conical sediment traps vary greatly, and the effects
266 of tilt toward and away from the flow also varied with the shape of the sediment trap
267 (Gardner, 1985, 2000). Differences in the POC flux between DSTs and MSTs were also
268 reported for the Sts. K2 and S1. Thus, the DSTs collected three to four times more mean
269 POC flux than the MSTs (Honda et al., 2016). Based on ^{210}Pb flux measurements,

Honda and Kawakami (2014) reported that the trapping efficiency of MSTs at 500 m was only approximately 20% at K2. Thus, the POC flux at 200 m is likely an underestimate of the true flux, and the flux collected using DSTs is considered closer to the true POC flux than that collected by the MSTs (Honda et al., 2016).

If we apply POC flux data using DSTs, the composition of the ZSB to the total C flux (= POC flux + ZSB) was 85.1% at K2 and 47.3% at S1 (Table 3). Thus, ZS constituted a large proportion of the total C flux for both locations. From oceans worldwide, the mean contribution of the ZSB to the total C flux for shallow traps (<200 m) is reported to be 30–90%, while for deeper traps (450–1000 m depth) it ranges from 24–47% (Buesseler et al., 2007). In the subtropical Bermuda Atlantic Time-series Study (BATS), the ZSB composed 49% of the total C flux (Owen et al., 2013). This value is close to our subtropical S1 value (47.3%). Screening and wet-picking are two methods for removing ZS from sediment trap samples. For the subtropical BATS, the ZSB contribution to the total C flux was small at less than 350 μm, and differences were not detected between screening by 350 μm mesh and wet-picking on whole samples (Owen et al., 2013). In this study, since we applied 1 mm mesh to separate the POC flux (<1 mm) and ZS (>1 mm), small ZS (under <1 mm) may cause an underestimation of the

ZSB, especially for the subtropical S1. For the subarctic K2, the high composition of large-sized Copepoda in the ZSB (Fig. 2B, Table 4) suggests ZSB underestimation would be minor.

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414 **Figure captions**

415 **Fig. 1.** Location of sampling stations: K2 in the subarctic and S1 in the subtropical
416 western North Pacific. Approximate directions of current flows are shown with
417 arrows (cf. Yasuda, 2003).

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

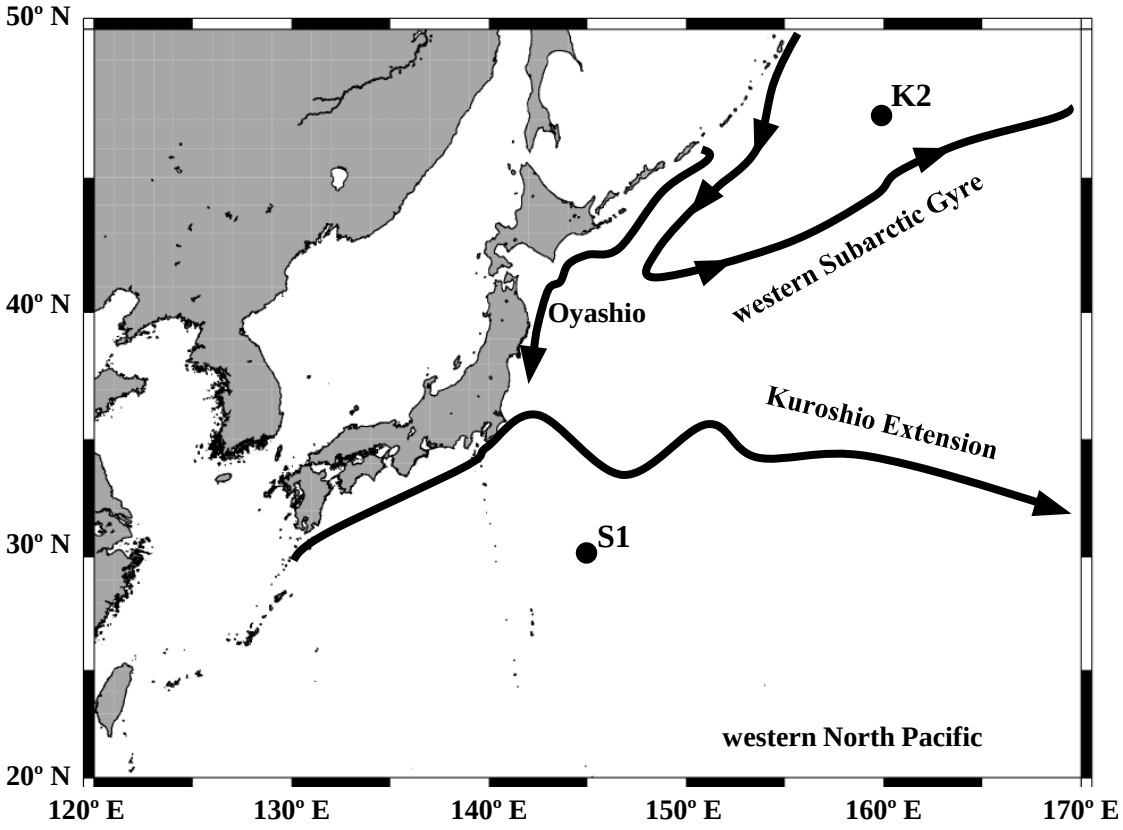
425 **Fig. 3.** Results of cluster analyses of the zooplankton swimmer abundance (ZSA, A)
426 and biomass (ZSB, B) at 200 m at the St. K2 in the western subarctic Pacific
427 from 25 July 2013 to 8 May 2014. Four and three groups were identified for
428 the ZSA and the ZSB, respectively. The ZSA and the ZSB of each taxon are
429 shown with colored bars.

430 **Fig. 4.** The zooplankton swimmer abundance (A) and biomass (B) collected at 200 m

at the St. S1 in the western subtropical Pacific from 18 July 2013 to 4 July 2014. The line with an open circle indicates the total zooplankton swimmer abundance or biomass, and the fills indicate percentage composition of the different taxa. Based on the cluster analysis, samples were separated into four (A–D) groups (cf. Fig. 5).

Fig. 5. Results of the cluster analysis on the zooplankton swimmer abundance (ZSA, A) and biomass (ZSB, B) at 200 m at the St. S1 in the western subtropical Pacific from 18 July 2013 to 4 July 2014. For both the ZSA and the ZSB, four groups (A–D) were identified. The ZSA and the ZSB of each taxon are shown with colored bars.

Fig. 6. Inter-regional comparison of taxonomic composition regarding zooplankton swimmer abundance (A) and biomass (B) collected at 200 m depths for the subarctic K2 (○) and the subtropical S1 (●) in the western North Pacific. Symbols and bars indicate annual means and standard deviations for each station. Inter-regional differences were tested using the *U*-test. **: $p<0.01$, ***: $p<0.001$, NS: not significant.



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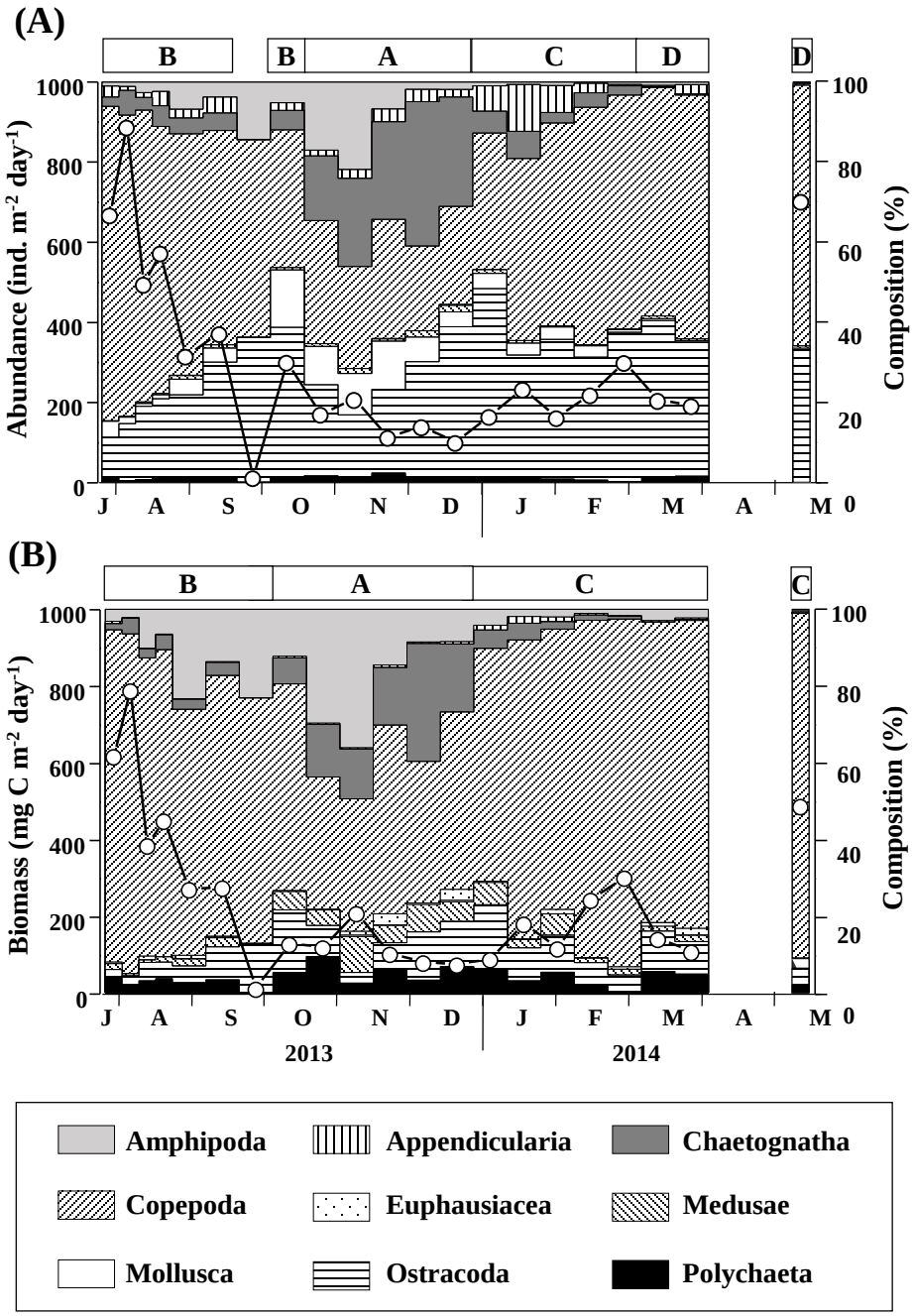

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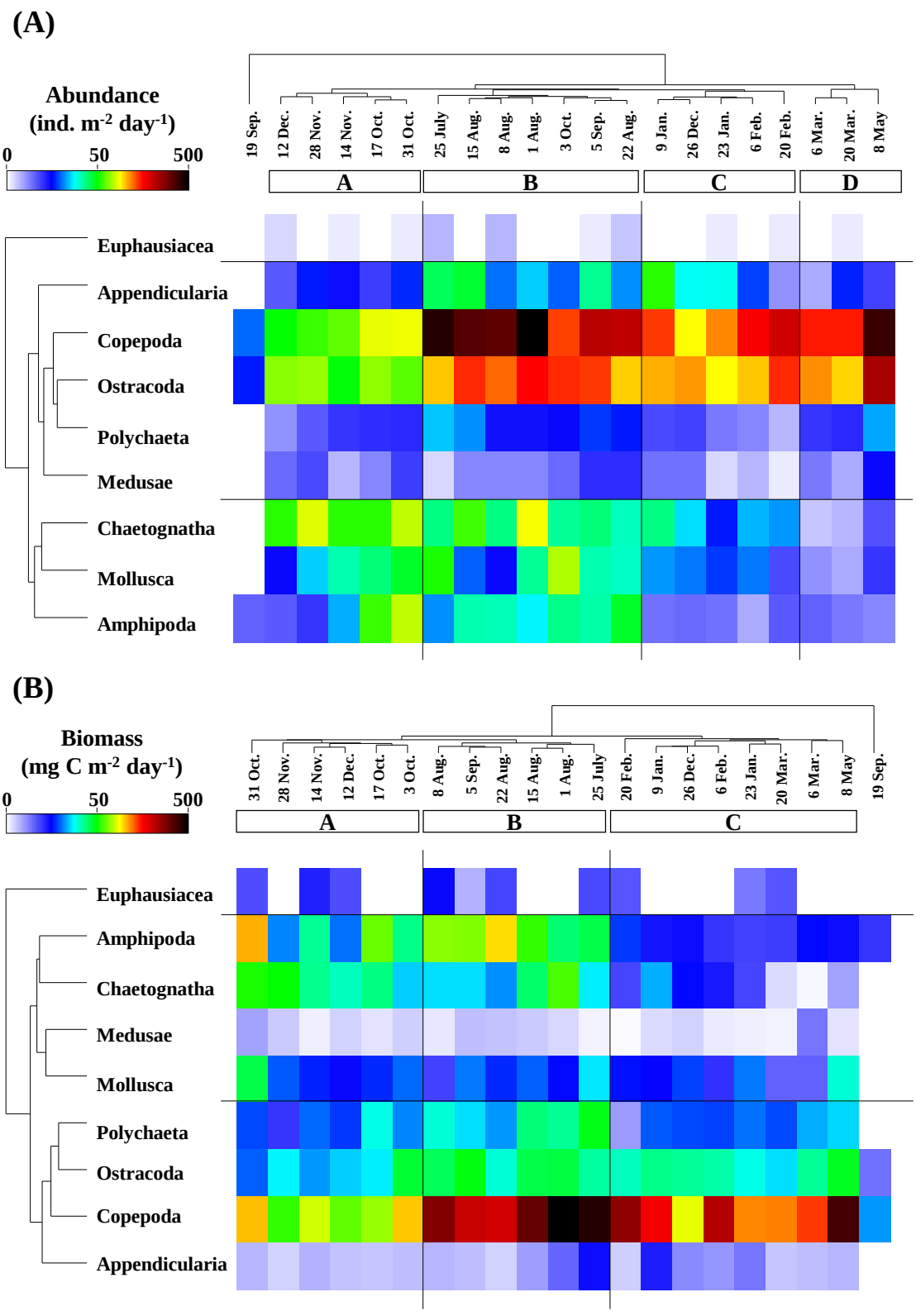

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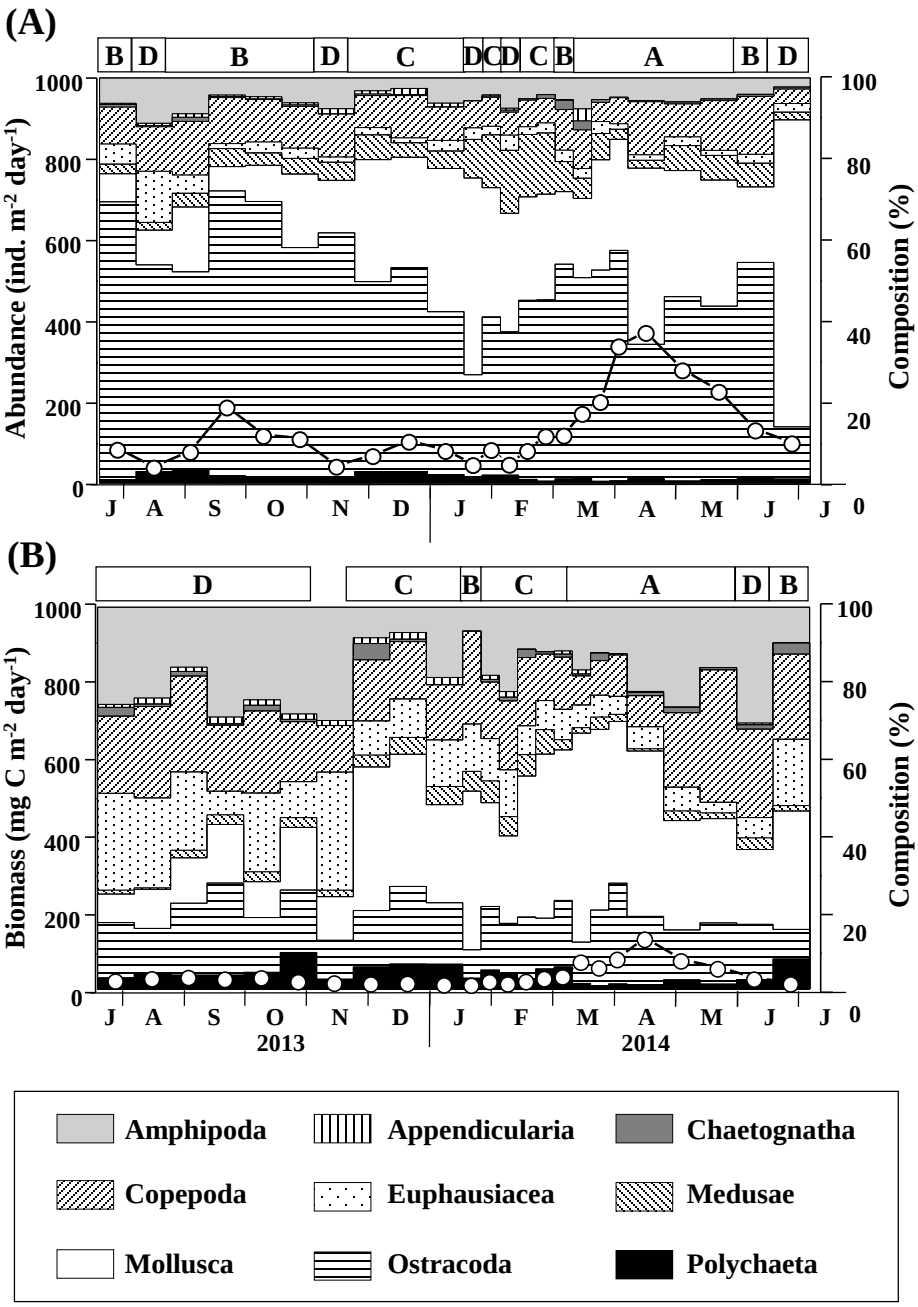

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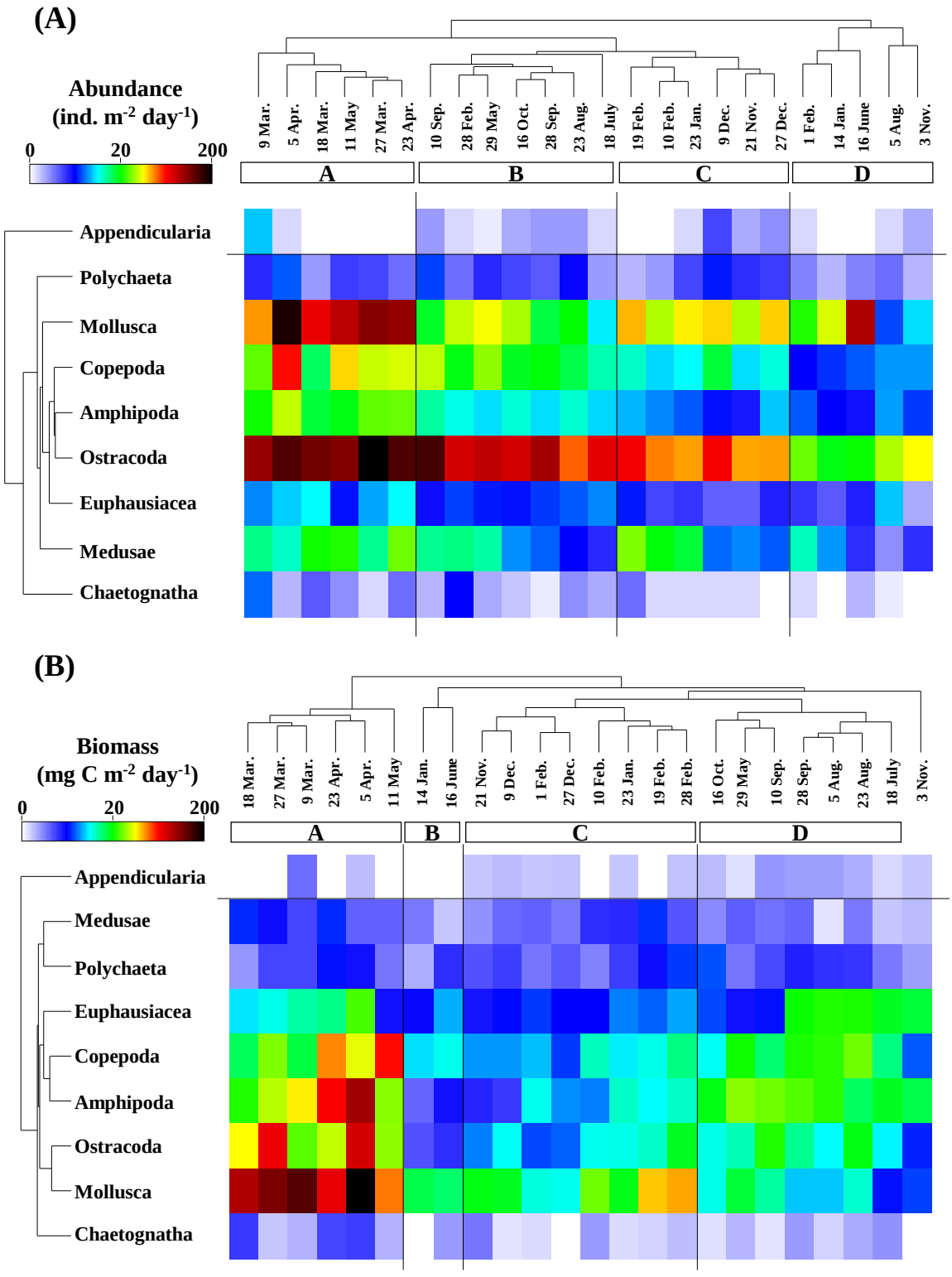

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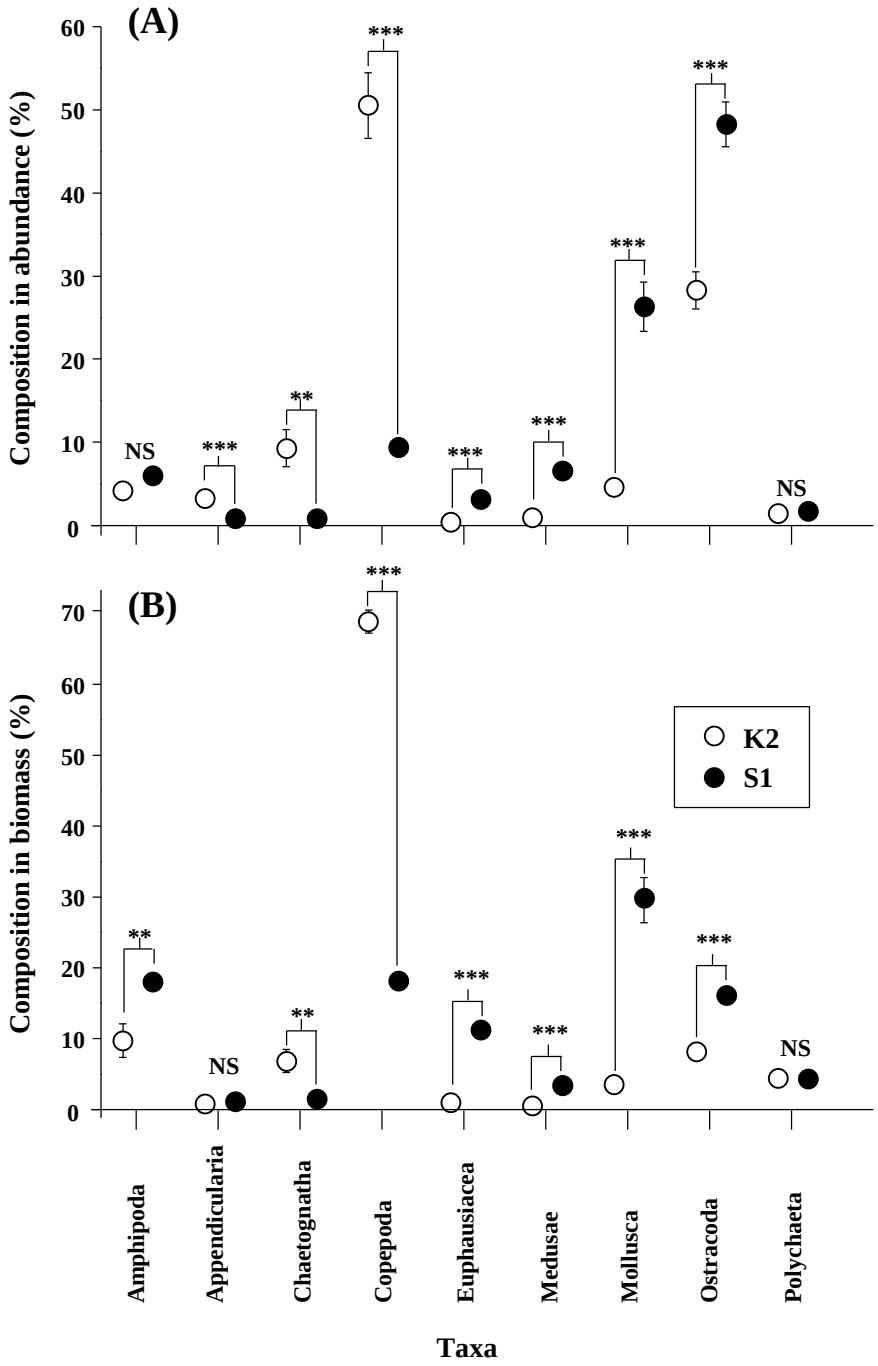

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Table 1. Sampler rotation timings of moored sediment traps (MSTs) and deployed timings of drifting sediment traps (DSTs) at the St. K2 (47°N, 160° E) in the subarctic and the St. S1 (30°N, 145°E) in the subtropical western North Pacific. Dates were 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)		

Table 2. Results of inter-regional comparison in the zooplankton swimmer abundance (ZSA) and biomass (ZSB) collected at 200 m depths between the subarctic K2 and the subtropical S1 in the western North Pacific. Inter-regional differences were tested using U-test. *: $p < 0.05$, **: $p < 0.01$, ns: not significant.

Taxon	ZSA	ZSB
Amphipoda	ns	ns
Appendicularia	* (K2>S1)	ns
Chaetognatha	** (K2>S1)	** (K2>S1)
Copepoda	** (K2>S1)	** (K2>S1)
Euphausiacea	* (S1>K2)	ns
Medusae	ns	ns
Mollusca	ns	ns
Ostracoda	ns	ns
Polychaeta	ns	ns

Table 3. Comparisons of the flux of particulate organic carbon (POC), the zooplankton swimmer biomass (ZSB) and the total carbon (total C) at 200 m depths of the subarctic K2 and the subtropical S1 in the western North Pacific. The POC fluxes were quantified by the two trap types—moored sediment traps (MSTs) and drifting sediment traps (DSTs)—while the ZSB was quantified using only MSTs. Note that the total C flux using DSTs was calculated using ZSB data from the MSTs. Values are the means±sd. All POC flux data were cited by Honda et al. (2016).

Station	Type of sediment trap	Flux (mg C m^{-2} day^{-1})			Composition of the ZSB to the total C flux (%)
		(A) POC	(B) ZSB	Total C (A+B)	
K2	MST	15.0	258.3±44.1	273.3	94.5
	DST	45.2		303.5	85.1
S1	MST	12.5	37.8±5.9	50.3	75.1
	DST	42.1		79.9	47.3

Table 4. List of calanoid copepods for zooplankton swimmers at 200 m at the St. K2 in the western subarctic Pacific from 25 July 2013 to 8 May 2014. Values are the mean ± SD for the annual mean zooplankton swimmer abundance (ZSA, ind. m^{-2} day^{-1}) and biomass (ZSB, mg C m^{-2} day^{-1}). Parentheses indicate percentage composition. ●: large-sized suspension-feeding copepods that undergo seasonal ontogenetic vertical migration.

Species	ZSA	ZSB
Eucalanus bungii ●	99.5±29.5 (51.5)	105.8±32.1 (53.5)
Neocalanus cristatus●	18.9±4.3 (9.8)	43.0±10.6 (21.7)
Paraeuchaeta elongata	25.1±3.0 (13.0)	22.9±3.0 (11.6)
Neocalanus plumchrus●	29.5±10.3 (15.2)	16.0±6.3 (8.1)
Racovitzanus sp.	6.6±1.23 (3.4)	1.8±0.3 (0.9)
Metridia pacifica	4.7±0.6 (2.5)	1.7±0.2 (0.8)
Gaetanus simplex	4.4±0.7 (2.3)	2.1±0.3 (1.1)
Gaidius variabilis	1.4±0.5 (0.7)	0.83±0.4 (0.4)
Pleuromamma scutullata	1.0±0.3 (0.5)	0.5±0.1 (0.3)
Candacia bipinnata	1.0±0.1 (0.5)	1.0±0.2 (0.5)
Neocalanus flemingeri ●	0.6±0.3 (0.3)	1.3±0.74 (0.6)
Heterorhabdus tanneri	0.5±0.2 (0.2)	0.3±0.1 (0.2)
Other Copepoda	0.4±0.1 (0.2)	0.5±0.1 (0.2)