

1 **Short-term changes of the mesozooplankton community**  
2 **and copepod gut pigment in the Chukchi Sea in autumn:**  
3 **Reflection of strong wind event**

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14  
15 **Abstract**

16 To evaluate the effect of atmospheric turbulence on the marine ecosystem, high-frequency  
17 sampling (two to four times per day) on the mesozooplankton community and the gut pigment  
18 of dominant copepods were made at a fixed station in the Chukchi Sea from 10 to 25  
19 September 2013. During the study period, a strong wind event (SWE) was observed on 18  
20 September. After the SWE, the standing stock of chlorophyll *a* (chl. *a*) was increased,  
21 especially for micro-size (> 10 μm) fractions. Zooplankton abundance ranged from 23610 to  
22 56809 ind. m<sup>-2</sup> and exhibited no clear changes with SWE. In terms of abundance, calanoid  
23 copepods constituted the dominant taxa (mean: 57%), followed by barnacle larvae (31%).  
24 Within the calanoid copepods, small-sized *Pseudocalanus* spp. (65%) and large-sized *Calanus*  
25 *glacialis* (30%) dominated. In the population structure of *C. glacialis*, copepodid stage 5 (C5)  
26 dominated, and the mean copepodid stage did not vary with SWE. The dominance of  
27 accumulated lipids in C5 and C6 females with immature gonads indicated that they were  
28 preparing for seasonal diapause. The gut pigment of *C. glacialis* C5 was higher at night and  
29 was correlated with ambient chl. *a*, and a significant increase was observed after SWE (2.6 vs

1 4.5 ng pigment ind.<sup>-1</sup>). The grazing impact by *C. glacialis* C5 was estimated to be 4.14 mg C  
2 m<sup>-2</sup> day<sup>-1</sup>, which corresponded to 0.5–4.6% of the standing stock of micro-size phytoplankton.  
3 Compared with the metabolic food requirement, their feeding on phytoplankton accounted for  
4 12.6% of their total food requirement. These facts suggest that *C. glacialis* could not  
5 maintain their population on solely phytoplankton food, and other food sources (i.e.,  
6 microzooplankton) are important in autumn. As observed for the increase in gut pigment,  
7 temporal phytoplankton bloom, which is enhanced by the atmospheric turbulence (SWE) in  
8 autumn, may have a positive effect on copepod nutrition.

9

## 10 **1 Introduction**

11 In marine ecosystems of the western Arctic Ocean, mesozooplankton is an important food  
12 resource for pelagic fishes and whales (Lowry et al., 2004; Ashjian et al., 2010). In terms of  
13 biomass, mesozooplankton in the western Arctic Ocean is dominated by Arctic copepods.  
14 Within the Arctic copepods, *Calanus glacialis* is a key species that dominates in the  
15 zooplankton biomass and commonly occurs in the continental shelf throughout the Arctic  
16 Ocean (Conover and Huntley, 1991; Lane et al., 2008). For the life cycle of *C. glacialis*, they  
17 grow to C3–C4 at the epipelagic layer during the first summer, then descend to the deep layer  
18 and enter diapause, developing to C5 at the epipelagic layer in the second summer, then down  
19 to the deep layer and molting to the adult stage (C6) using stored lipid as energy (Longhurst et  
20 al., 1984; Ashjian et al., 2003; Falk-Petersen et al., 2009). Concerning seasonal change, a  
21 comparison of the zooplankton community between summer and autumn (Llinás et al., 2009)  
22 and year-round changes based on the two-week sampling interval at a drifting ice station in  
23 the Arctic basin were reported (Ashjian et al., 2003). However, short-term changes in the  
24 zooplankton community based on high-frequency sampling (two to four times per day) have  
25 not been reported.

26 Recently, a drastic reduction in the area of sea ice has been observed in the Arctic  
27 Ocean during summer, and the sea ice reduction was greatest in the western Arctic Ocean  
28 (Stroeve et al., 2007; Comiso et al., 2008; Markus et al., 2009). Furthermore, increases in  
29 frequency and magnitude of cyclones and a northward shift of their track during summer have  
30 been reported in recent years (Serreze et al., 2000; Cabe et al., 2001; Zhang et al., 2004; Sepp  
31 and Jaagus, 2011). While the importance of such changes is clear, little information is  
32 available regarding their effect on atmospheric turbulence in marine ecosystems in the

1 western Arctic Ocean. From 10 to 25 September 2013, high-frequency sampling/observation  
2 was made at a fixed station in the Chukchi Sea, and the occurrence of strong wind events  
3 (SWE), vertical flux of nutrients and changes in primary production and microplankton  
4 communities were reported (Nishino et al., 2015; Yokoi et al., submitted). However, no  
5 information is available regarding how the mesozooplankton community responds to such  
6 atmospheric turbulence and oceanic environmental changes.

7 In the present study, we evaluated short-term changes of the mesozooplankton  
8 community in the Chukchi Sea during autumn based on the high-frequency samplings made  
9 simultaneously by Nishino et al. (2015) and Yokoi et al. (submitted). We estimated the  
10 grazing impact of dominant copepods based on their gut pigments and evaluated the effect of  
11 SWE (Nishino et al., 2015) and short-term changes of microplankton assemblages (Yokoi et  
12 al., submitted) on the mesozooplankton community in the Chukchi Sea in autumn.

## 14 **2 Materials and Methods**

### 15 **2.1 Field sampling**

16 Zooplankton samplings were conducted at a fixed station in the Chukchi Sea (72°45'N,  
17 168°15'W, depth 56 m) from 10 to 25 September 2013 (Fig. 1) (Nishino et al., 2015).  
18 Zooplankton samples were collected by vertical hauls with a NORPAC net (mouth diameter  
19 45 cm, mesh size 335  $\mu\text{m}$ ; Motoda, 1957) and ring net (mouth diameter 80 cm, mesh size 335  
20  $\mu\text{m}$ ) from 49 m depth to the sea surface two to four times per day (total of 47 times) including  
21 both day and night. The large mesh size of NORPAC net (335  $\mu\text{m}$ ) may induce somewhat  
22 underestimation of smaller zooplankton species and early stages of larger zooplankton species.  
23 Zooplankton samples collected by NORPAC nets were preserved with 5% buffered formalin  
24 immediately on board. The ring net samples were used for copepod gut pigment  
25 measurement. For evaluation of the diel vertical migration (DVM) of copepods, day and  
26 night vertical stratified hauls with closing PCP nets (mouth diameter 45 cm, mesh size 62  $\mu\text{m}$ ;  
27 Kawamura, 1989) from two layers (0–20 m and 20–49 m) were made on 14 and 22  
28 September. The samples from the PCP net were preserved with 5% buffered formalin.

29 At the fixed station, temperature, salinity and chlorophyll *a* (chl. *a*) fluorescence were  
30 measured by CTD (Sea-Bird Electronics Inc., SBE911Plus) casts at a frequency of two to four  
31 times per day. To evaluate size fractionated chl. *a*, water samples from the sea surface and

1 the maximum fluorescence layer (16.8–27.7 m depth) were collected by a bucket and rosette  
2 multi-sampler mounted on CTD, respectively. Water samples were filtered through 20, 10  
3 and 2- $\mu\text{m}$  pore-size membranes and GF/F filters, and chl. *a* was extracted with N,N-  
4 dimethylformamide and measured with a fluorometer (Turner Designs, Inc., 10-AU-005).

## 5 **2.2 Gut pigment**

6 For fresh samples collected by ring nets, 10% v/v soda (saturated  $\text{CO}_2$  in water) was added to  
7 avoid copepod grazing, gut evacuation and decomposition of gut pigment. Fresh specimens  
8 of *C. glacialis* copepodid stage 5 (C5) were sorted under a stereomicroscope. Batches of  
9 fifteen specimens were immersed in 6 ml N,N-dimethylformamide and stored in dark, cold  
10 conditions overnight to extract chlorophyll and phaeopigments. After the extraction of  
11 pigment, the chlorophyll and phaeopigments were measured with a fluorometer (Turner  
12 Designs, Inc., 10-AU-005). Chlorophyll and phaeopigments were summed and expressed as  
13 gut pigments ( $\text{ng pigment ind.}^{-1}$ ) (cf. Mackas and Bohrer, 1976).

14 The gut pigment of *C. glacialis* C5 was higher at nighttime than daytime. Assuming  
15 their grazing at night, the grazing rate ( $GR_{ind.}$ ,  $\text{mg pigment ind.}^{-1} \text{ day}^{-1}$ ) of *C. glacialis* C5 was  
16 calculated from following equation:

$$17 \quad GR_{ind.} = GP \times k \times T / 10^6, \quad (1)$$

18 where  $GP$  is the individual gut pigment at night ( $\text{ng pigment ind.}^{-1}$ ),  $k$  is the gut evacuation  
19 rate ( $0.017 \text{ min}^{-1}$ , Tande and Båmstedt, 1985), and  $T$  is the length of the nighttime (mean 13  
20 hours = 780 min during study period). The grazing impact of *C. glacialis* C5 on micro-size ( $>$   
21  $10 \mu\text{m}$ ) chl. *a* ( $GI$ , % on chl. *a* standing stock  $\text{day}^{-1}$ ) was calculated by the following equation:

$$22 \quad GI = GR_{ind.} \times N / \text{Int. chl. } a \times 100, \quad (2)$$

23 where  $N$  is the abundance of *C. glacialis* C5 ( $\text{ind. m}^{-2}$ ), and  $\text{Int. chl. } a$  is standing stock of  
24 large-sized ( $> 10 \mu\text{m}$ ) chl. *a* ( $\text{mg m}^{-2}$ ).

## 25 **2.3 Zooplankton community**

26 In the land laboratory, identification and enumeration by taxa were performed on zooplankton  
27 samples collected by NORPAC nets under a stereomicroscope. For dominant taxa (calanoid  
28 copepods), identification was made to species and copepodid stage levels. For species  
29 identification of calanoid copepods, we referred mainly to Brodsky (1967) and Frost (1974)

1 for *Calanus* spp., Miller (1988) for *Neocalanus* spp. and Frost (1989) for *Pseudocalanus* spp.  
2 For *Pseudocalanus* spp., species identification was made only for late copepodid stage C5  
3 females/males (C5F/M) and C6F/M, and their early copepodid stages (C1–C4) were treated  
4 as *Pseudocalanus* spp.

5 For the evaluation of the DVM of large dominant copepods, we enumerated *C.*  
6 *glacialis* from PCP net samples. For *C. glacialis*, the lipid accumulation of C5 was scored  
7 into three categories: I (the oil droplet length (ODL) was 0–4% of the prosome length (PL)),  
8 II (ODL was 4–40% of PL) and III (ODL was > 40% of PL). Gonad maturation of *C.*  
9 *glacialis* C6F was also scored into three categories: I (immature), II (small oocytes in the  
10 ovary or oviduct) and III (large eggs or distended opaque filled-in oviduct). For this gonad  
11 maturation index, we cited those for *C. hyperboreus* (Hirche and Niehoff, 1996).

12 A species diversity index ( $H'$ ) in each sample was calculated using the equation:

$$13 \quad H' = -\sum n/Ni \times \ln n/Ni$$

14 where  $n$  is the abundance (ind.  $m^{-2}$ ) of  $i$ th species and  $Ni$  is the abundance (ind.  $m^{-2}$ ) of total  
15 calanoid copepods in the sample (Shannon and Weaver, 1949). Pielou evenness ( $J'$ ) was also  
16 calculated using the equation:

$$17 \quad J' = H' / \ln(s)$$

18 where  $s$  is total number of observed species in the community (Pielou, 1966).

19 From NORPAC net samples, the mean copepodid stage ( $MCS$ ) of *C. glacialis* was  
20 calculated from the following equation:

$$21 \quad MCS = \frac{\sum_{i=1}^6 i \times Ai}{\sum_{i=1}^6 Ai}, \quad (3)$$

22 where  $i$  is the number of the copepodid stage (1–6 indicates C1–C6), and  $Ai$  (ind.  $m^{-2}$ ) is the  
23 abundance of the  $i$ th copepodid stage (cf. Marin, 1987).

24 During the study period, SWE was observed from 18 to 19 September (Nishino et al.,  
25 2015). To evaluate the effect of SWE, the abundances of each zooplankton taxon and species  
26 were compared between “before SWE (10–18 September)” and “after SWE (19–25  
27 September)” using the  $U$ -test. This statistical analysis was performed with Stat View.

## 1 **3 Results**

### 2 **3.1 Hydrography and chlorophyll a**

3 During the sampling period, the temperature ranged from  $-1.5^{\circ}\text{C}$  to  $3.3^{\circ}\text{C}$ , and thermocline  
4 was observed at a depth of approximately 25 m (Fig. 2a). Cold water below  $0^{\circ}\text{C}$  continuously  
5 occurred below thermocline, whereas the temperature above thermocline decreased from 3.3  
6 to  $1.5^{\circ}\text{C}$  during the study period (Fig. 2a). Salinity ranged from 31.1 to 32.8, and halocline  
7 was observed at approximately 25 m, which was parallel to thermocline (Fig. 2b). Salinity  
8 below halocline was constant ca.  $> 32$ , whereas salinity in the upper layer increased from 31.1  
9 to 31.6 throughout the study period. Chl. *a* ranged from 0.08 to  $3.25 \text{ mg m}^{-3}$  and increased  
10 after the SWE (Fig. 2c). The T-S diagram showed that the hydrographic conditions in the  
11 upper layer changed temporally; thus, temperature decreased while salinity increased during  
12 the study period (Fig. 2d).

### 13 **3.2 Zooplankton community**

14 Zooplankton abundance ranged from 23610 to 56809 ind.  $\text{m}^{-2}$ , and calanoid copepods and  
15 barnacle larvae composed 57% and 31% of the community, respectively (Table 1). For  
16 calanoid copepods, 15 species belonging to nine genera were identified. Within them,  
17 *Pseudocalanus* spp. and *C. glacialis* dominated and composed 65% and 30% of the total  
18 copepods, respectively. Shannon species diversity and Pielou evenness for the copepods  
19 community were  $1.87 \pm 0.12$  and  $0.81 \pm 0.06$ , respectively. According to a comparison of time  
20 periods before and after the SWE, the total zooplankton abundance, the Shannon species  
21 diversity and the Pielou evenness did not change, whereas one calanoid copepod *Centropages*  
22 *abdominalis* and cyclopoid copepods increased after the SWE (Table 1). On the other hand,  
23 one calanoid copepod *Metridia pacifica*, appendicularians, barnacle larvae, euphausiids and  
24 gymnosomes (*Clione limacina*) decreased after the SWE.

### 25 **3.3 Calanus glacialis**

26 Throughout the study period, the standing stock of *C. glacialis* ranged from 1990 to 14554  
27 ind.  $\text{m}^{-2}$ , and no significant changes were detected with the SWE (Fig. 3a, Table 1). For the  
28 population structure, all copepodid stages (C1 to C6F/M) occurred, and C5 was the most  
29 dominant stage (36%) of the population (Fig. 3). The MCS did not vary with SWE (Fig. 3a).

1 Throughout the study period, the lipid accumulation of C5 was high (Fig. 3b), and the gonad  
2 maturation of C6F was dominated by immature specimens (Fig. 3c). These parameters  
3 exhibited no significant change with the SWE ( $U$ -test,  $p = 0.285$ – $0.303$ ).

4 On both 14 and 22 September, the C1–C4 and C5 populations of *C. glacialis* occurred  
5 mainly at lower layers (20–49 m) during the daytime, and they migrated to upper layers (0–20  
6 m) at night (Fig. 4). It should be noted that nearly half of C5 remained in the lower layer both  
7 day and night. Lipid accumulation was higher for the C5 population residing in the lower  
8 layer. C6F occurred at a lower layer throughout the day.

9 The gut pigment of *C. glacialis* C5 ranged from 0.6 to 12.3 ng pigment ind.<sup>-1</sup> and  
10 showed a significant increase after the SWE (mean values: 2.6 vs 4.5 ng pigment ind.<sup>-1</sup>,  $U$ -  
11 test,  $p < 0.01$ ) (Fig. 5a). In a comparison between day and night, most dates except 18 and 23  
12 September showed high gut pigment levels at night by a factor of two to five times those of  
13 the daytime. In both day and night, the gut pigments were correlated with a standing stock of  
14 chl. *a* ( $p < 0.05$ ) (Fig. 5b).

15 The population grazing rate of *C. glacialis* C5 ranged from 0.04–0.28 mg pigment m<sup>-2</sup>  
16 day<sup>-1</sup>, peaked on 20 September (Fig. 6a) and increased significantly after the SWE (0.11 vs  
17 0.18 mg pigment m<sup>-2</sup> day<sup>-1</sup>,  $U$ -test,  $p < 0.05$ ). During the study period, chl. *a* peaked at 18  
18 September, and micro-size (> 10 μm) dominated (54% of total chl. *a*), especially after the  
19 SWE (66%) (Fig. 6b). The grazing impact of *C. glacialis* C5 on micro-size chl. *a* ranged  
20 from 0.5–4.6% on chl. *a* standing stock day<sup>-1</sup> and was high before the SWE from 10 to 15  
21 September (Fig. 6c).

22

## 23 **4 Discussion**

### 24 **4.1 Zooplankton community**

25 The zooplankton community in the Chukchi Sea is known to have large spatial and temporal  
26 changes (Springer et al., 1989; Llinás et al., 2009; Matsuno et al., 2011). Total zooplankton  
27 abundance in this study was approximately half (mean: 34059 ind. m<sup>-2</sup>) the abundance  
28 reported by Matsuno et al. (2012) on the Chukchi shelf (mean: 75683 ind. m<sup>-2</sup>), with low  
29 abundance of small copepods (*Pseudocalanus* spp. and cyclopoids) and the remarkable  
30 absence of the Arctic copepod *Metridia longa*. For the hydrography of this station, Nishino et

1 al. (2015) noted that the upper warm and less saline water was the Pacific Summer water,  
2 which was transported to the Arctic Ocean during summer, and the cold saline water of the  
3 lower layer was the remnant brine of the Pacific Winter water, which was transported to the  
4 Arctic Ocean during winter. Geographically, the present station was located at a main stream  
5 of the Pacific water (Weingartner et al., 2005). The high abundance of the Pacific copepod *M.*  
6 *pacifica* and *Neocalanus* spp. and the lack of the occurrence of the Arctic *M. longa* in this  
7 study was thought to be a reflection of the water mass covering the station. Because of these  
8 reasons (less small copepods and high abundance of Pacific copepods), the Shannon species  
9 diversity and Pielou evenness in this study (1.87 and 0.81) are higher than the reported values  
10 for the whole Chukchi Sea (1.79 and 0.62 calculated from Matsuno et al., 2012).

11 Seasonal characteristics during summer included the dominance of the meroplankton  
12 (barnacle and bivalve larvae), which composed 39% of zooplankton abundance (Hopcroft et  
13 al., 2010). Dominance of the barnacle larvae also occurred in this study (Table 1). Benthic  
14 barnacle adults release their larvae when they meet phytoplankton blooms (Crisp, 1962; Clare  
15 and Walker, 1986), and their larvae spend two to three weeks in the water column and then  
16 settle (Herz, 1933). The abundance of barnacle larvae in this study (mean 10430 ind. m<sup>-2</sup>)  
17 was 13–55% lower than that in summer (19114–79899 ind. m<sup>-2</sup>, Matsuno et al., 2011). It also  
18 should be noted that the abundance of barnacle larvae decreased significantly during the study  
19 period (Table 1). These facts suggest that most of the barnacle larvae may have ended the  
20 planktonic phase and settled to the sea bottom during the study period (autumn).

21 Concerning the effect of the SWE, a few taxa and species showed significant changes  
22 in abundance (Table 1). For dominant species, cyclopoid copepods were increased after the  
23 SWE (Table 1). The generation length of cyclopoid copepods was reported to be two to three  
24 months in the Arctic Ocean (Dvoretsky and Dvoretsky, 2009). In ambient temperature (–1.5  
25 to 3.3°C), the egg hatching of this taxon is estimated to be 11–41 days (Nielsen et al., 2002).  
26 These facts suggest that the increase of cyclopoid copepods would not be caused by their  
27 reproduction within the study period (16 days). As an alternative cause, the horizontal  
28 advection of the water mass during the study period, which was reported by Nishino et al.  
29 (2015), should be considered. These results suggest that the effect of SWE on zooplankton  
30 abundance was relatively small because of the longer generation length of mesozooplankton  
31 in this region.



## 1 **4.2 Population structure of *C. glacialis***

2 Concerning the population structure, Ashjian et al. (2003) reported that *C. glacialis* around the  
3 Northwind Abyssal Plain was dominated by C5 and C6F in September. In the present study,  
4 the population structure of *C. glacialis* was dominated by C5 (Fig. 3a), and their MCS  
5 (mean±sd: 3.77±0.20) was similar to the reported value for autumn in this region (3.58,  
6 Matsuno et al., 2012). Most of the C6F had immature gonads and no ovigerous C6Fs were  
7 observed (Fig. 3c). These results corresponded with the year-round observation around the  
8 Northwind Abyssal Plain (Ashjian et al., 2003). *Calanus glacialis* C6F is known to occur at  
9 the epipelagic layer in April, just before sea-ice melting (Kosobokova, 1999), and to  
10 reproduce with grazing ice algae and ice-edge bloom (Campbell et al., 2009). Thus, because  
11 this study period (September) greatly varied with regards to their reproduction period (April),  
12 most C6Fs were considered to have immature gonads when residing in the lower layer  
13 (diapause).

14 Nocturnal ascent DVM, which is related to nighttime grazing on phytoplankton, was  
15 reported for *C. glacialis* in the Arctic Ocean during spring and autumn (Runge and Ingram,  
16 1988; Conover and Huntley, 1991). In this study, DVM was observed for C3, C4 and C5 (Fig.  
17 4). At high-latitude seas, the magnitude of *Calanus* spp. DVM is known to vary with the  
18 season and copepodid stage, and their DVM intensity is greater during spring and autumn  
19 when the diel changes in light penetration are large (Falkenhaug et al., 1997). No DVM of  
20 *Calanus* spp. was reported for lipid accumulated C5 (Falk-Petersen et al., 2008). In the  
21 present study, nearly half of the C5 population, which was characterized as having a large  
22 lipid accumulation, remained in the lower layer throughout the day (Fig. 4). The deep C5  
23 population may have already completed lipid accumulation and ceased DVM in the study  
24 period (September), while the remaining C5 population with active DVM may have grazed on  
25 phytoplankton in the upper layer during the night and stored lipid in preparation for diapause.  
26 These results suggest that the *C. glacialis* population in this study was at the seasonal phase  
27 just before entering diapause, and this interpretation corresponded well with their life cycle in  
28 this region (Ashjian et al., 2003).

## 29 **4.3 Grazing of *C. glacialis***

30 The gut pigment of *C. glacialis* in the Arctic Ocean is known to exhibit diel changes and  
31 higher levels at night than in the daytime (Conover and Huntley, 1991). Higher gut pigment  
32 levels at night were also observed in this study (*U*-test,  $p < 0.001$ ) (Fig. 5a). Their gut

1 pigments were correlated with the standing stock of chl. *a* (Fig. 5b) and increased during the  
2 high chl. *a* period after the SWE (Fig. 5a). These facts suggest that *C. glacialis* feeding  
3 responded to the small phytoplankton bloom, which was enhanced by the nutrient supply and  
4 vertical mixing caused by the SWE (Nishino et al., 2015; Yokoi et al., submitted).

5 Concerning gut pigment measurement, underestimation by decomposition of  
6 phytoplankton pigment through gut passage has been reported (Conover et al., 1986; Head,  
7 1992). This underestimation is reported to be ca. 0.1–10% of grazing (Conover et al., 1986)  
8 and varies with light conditions, grazing behavior and phytoplankton species (Head, 1992).  
9 To estimate the grazing impact, data on the gut evacuation rate ( $k$ ,  $\text{min}^{-1}$ ) is needed  
10 (Mauchline, 1998). The gut evacuation rate is known to have a positive correlation with  
11 temperature (Dam and Petersen, 1988). From the equation between  $k$  and temperature ( $T$ :  
12  $^{\circ}\text{C}$ ):  $k = 0.00941 + 0.002575T$  (Mauchline, 1998) and ambient temperature in this study ( $T$ :  
13  $-1.5$  to  $3.3^{\circ}\text{C}$ ),  $k$  would be estimated to be  $0.0055$ – $0.0179 \text{ min}^{-1}$ . This range covers the value  
14 applied in the present study ( $k = 0.017$ , Tande and Båmstedt, 1985). The value was also at the  
15 range observed by our independent laboratory experiments in September 2010 ( $0.006$ – $0.041$ ,  
16 Matsuno et al., unpublished data). These facts suggest that the value applied in this study ( $k =$   
17  $0.017$ ) was reasonable for *C. glacialis* in this region.

18 Assuming that half of the C5 population performed nocturnal ascent and grazing on  
19 phytoplankton at night, using C:Chl. *a* ratio (29.9, Sherr et al., 2003), the grazing impact ( $\text{mg}$   
20  $\text{C m}^{-2} \text{ day}^{-1}$ ) of *C. glacialis* C5 was calculated (Table 2). The grazing impact of this study  
21 was estimated to be  $4.14 \text{ mg C m}^{-2} \text{ day}^{-1}$ . In the Arctic Ocean, the grazing impact of  
22 copepods is greatly affected by the extent of sea-ice, environmental conditions and food  
23 concentration (Hirche et al., 1991; Campbell et al., 2009). The low grazing impact of this  
24 study may be caused by the low feeding activity of C5 just before their diapause and may also  
25 be related to the low ambient chl. *a* (mean:  $14.3 \text{ mg m}^{-2}$ ) during the study period.

26 We also estimated the food requirement of *C. glacialis* C5 to support their metabolism  
27 under ambient temperature (Ikeda and Motoda, 1978; Ikeda et al., 2001). The potential  
28 contribution of phytoplankton food to food requirements was 12.6% for *C. glacialis* C5  
29 (Table 2). This result indicates that *C. glacialis* C5 could not maintain its population solely  
30 on phytoplankton food; other food sources are important. Regarding food for *C. glacialis*,  
31 Campbell et al. (2009) reported that this species prefers microzooplankton rather than  
32 phytoplankton in the Chukchi Sea, and Levinsen et al. (2000) noted that the micro-size ( $> 10$   
33  $\mu\text{m}$ ) ciliates and dinoflagellates are important food sources during post-bloom. For the

1 microplankton community during the study period, Yokoi et al. (submitted) noted that not  
2 only diatoms (1.64–14.11 cells ml<sup>-1</sup>) but also dinoflagellates (0.54–2.42 cells ml<sup>-1</sup>) and  
3 ciliates (0.14–2.76 cells ml<sup>-1</sup>) were abundant. Thus, as food sources for *C. glacialis*,  
4 microzooplankton (dinoflagellates and ciliates) are considered to be important in the Chukchi  
5 Sea during autumn.

## 6 **5 Conclusions**

7 Throughout this study, short-term changes in the mesozooplankton community and the  
8 grazing impact of *C. glacialis* were evaluated in the Chukchi Sea during autumn. During the  
9 16-day sampling/observation period, the zooplankton community showed no clear changes  
10 related to the SWE and dominant copepods prepared for diapause (i.e., stored lipids in the  
11 pre-adult stage or adults with immature gonads). On the other hand, the feeding intensity of  
12 dominant copepods increased with the reflection of the temporal phytoplankton bloom, which  
13 was enhanced by the SWE (Nishino et al., 2015). Thus, the temporal phytoplankton bloom  
14 caused by the atmospheric turbulence (SWE) during autumn may have had a positive indirect  
15 effect on mesozooplankton (SWE → nutrient supply from the deep layer → small  
16 phytoplankton bloom → copepod feeding) within a short period. These facts suggest that  
17 some zooplankton may obtain benefit from an extension of the primary production season  
18 with more turbulence and later freeze-up of the Chukchi Sea.

## 19 **Author contributions**

20 S.N., J.I. and T.K. designed and coordinated this research project. S.N. and J.I. were chief  
21 scientists during the MR13-06 cruise of R.V. *Mirai*. K.M. collected the zooplankton samples,  
22 measured copepod gut pigments during the cruise and performed species identification and  
23 enumeration of the zooplankton samples in the land laboratory. K.M. and A.Y. wrote the  
24 manuscript with contributions from all co-authors.

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32

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24



1 **Figure captions**

2 **Figure 1.** Location of sampling station in the Chukchi Sea from 10 to 25 September 2013.  
3 Arrows indicate major current flows in this region (cf. Grebmeier, 2012).

4 **Figure 2.** Temporal changes in temperature (a), salinity (b), chlorophyll *a* (c) and T-S  
5 diagram (d) at a fixed-station in the Chukchi Sea from 10 to 25 September 2013.

6 **Figure 3.** *Calanus glacialis*: temporal changes in the population structure (a), lipid  
7 accumulation of C5 (b) and gonad maturation of C6F (c) at a fixed station in the  
8 Chukchi Sea from 10 to 25 September 2013.

9 **Figure 4.** Diel vertical distribution of *Calanus glacialis* at a fixed-station in the Chukchi Sea,  
10 14 and 22 September 2013. For C5, the mean lipid accumulation score (1–3) is also  
11 shown. Note that no C6Ms were collected.

12 **Figure 5.** *Calanus glacialis*: temporal and diel changes in the gut pigment of C5 (a) at a fixed  
13 station in the Chukchi Sea from 10 to 25 September 2013. The relationship between  
14 the gut pigment of C5 and standing stock chlorophyll *a* (b). Dotted and dashed lines  
15 indicate regressions for day and night, respectively. For (b), “whole” indicates  
16 including all data, both day and night. \*\*:  $p < 0.01$ , \*:  $p < 0.05$ .

17 **Figure 6.** Temporal changes in the grazing rate of *Calanus glacialis* C5 (a), integrated size-  
18 fractionated chlorophyll *a* (b) and the grazing impact of *C. glacialis* C5 on micro-  
19 phytoplankton ( $> 10 \mu\text{m}$ ) (c) at a fixed station in the Chukchi Sea from 10 to 25  
20 September 2013.

21

1 **Table 1.** List of mesozooplankton taxa and calanoid copepod species and their mean  
2 abundances (ind. m<sup>-2</sup>) at a fixed station in the Chukchi Sea from 10 to 18 September,  
3 before the strong wind event (SWE), and 19–25 September (after the SWE), 2013.  
4 For calanoid copepods, Shannon species diversity and Pielou evenness were  
5 calculated. Differences between the two periods (before vs. after the SWE) were  
6 tested with the *U*-test. \*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.0001$ , NS: not significant.

Species/taxa Community parameters	Before SWE (10–18 Sep.)	After SWE (19–25 Sep.)	<i>U</i> -test
Calanoid copepods			
<i>Acartia longiremis</i>	604	542	NS
<i>Calanus glacialis</i>	6714	5658	NS
<i>Calanus hyperboreus</i>	0	5	NS
<i>Centropages abdominalis</i>	9	29	*
<i>Eucalanus bungii</i>	6	6	NS
<i>Eurytemora herdmani</i>	0	2	NS
<i>Metridia pacifica</i>	251	154	*
<i>Microcalanus pygmaeus</i>	6	3	NS
<i>Neocalanus cristatus</i>	6	5	NS
<i>Neocalanus flemingeri</i>	46	65	NS
<i>Neocalanus plumchrus</i>	12	15	NS
<i>Pseudocalanus acuspes</i>	3393	3254	NS
<i>Pseudocalanus mimus</i>	1194	1296	NS
<i>Pseudocalanus minutus</i>	2178	2387	NS
<i>Pseudocalanus newmani</i>	2805	2774	NS
<i>Pseudocalanus</i> spp. (C1–C4)	2758	2980	NS
Cyclopoid copepods	511	1153	**
Poecilostomatoid copepods	0	3	NS
Amphipoda	9	5	NS
Appendicularia	707	442	*

Barnacle larva	12118	8945	***
Chaetognatha	1281	1039	NS
Echinodermata larva	31	61	NS
Eubrachyura zoea	41	26	NS
Euphausiacea	18	3	*
Gymnosomata	172	84	**
Hydrozoa	209	205	NS
Isopoda	3	3	NS
Polychaeta	1124	1005	NS
Thecosomata	16	8	NS
Total zooplankton	36223	32154	NS
Shannon species diversity	1.85	1.90	NS
Pielou evenness	0.80	0.82	NS

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1

2

1 **Table 2.** *Calanus glacialis*: Comparison of food requirements (ingestion) and grazing rate on  
 2 phytoplankton and the proportion of phytoplankton food in the Chukchi Sea from 10  
 3 to 25 September 2013. Food requirements were calculated from the metabolism,  
 4 which was estimated by the body mass, temperature (Ikeda et al., 2001), respiratory  
 5 quotient (Gnaiger, 1983) and individual carbon budget (Ikeda and Motoda, 1978).  
 6 For details on the values used in this calculation, see the footnotes.

Day/night (depth, temp.: $T$ , period)	Flux ( $\text{mg C m}^{-2} \text{ day}^{-1}$ )			Proportion of phytoplankton food (%: B/A)
	Metabolism	Food requirement (ingestion) (A)	Grazing rate on phytoplankton (B)	
Day-lower layer (20–49 m, $-0.74^\circ\text{C}$ , 11 h)	5.64	14.11	–	–
Night-upper layer (0–20 m, $2.31^\circ\text{C}$ , 13 h)	4.12	10.29	–	–
Night-lower layer (20–49 m, $-0.74^\circ\text{C}$ , 13 h)	3.34	8.34	–	–
Daily-water column	13.10	32.74	4.14	12.6

7 Dry mass ( $DM$ :  $\text{mg ind.}^{-1}$ ) of *C. glacialis* C5 was 0.654 (Matsuno et al., unpublished data).

8 Oxygen consumption ( $\mu\text{L O}_2 \text{ ind.}^{-1} \text{ h}^{-1}$ ) =  $\exp(-0.399+0.801 \times \text{Ln}(DM)+0.069 \times T)$  (Ikeda et al.,  
 9 2001).

10 Respiratory quotient ( $[\text{CO}_2/\text{O}_2]$ ) was assumed to be 0.97 (Gnaiger, 1983).

11 Metabolism was assumed to be 0.4 (40%) of ingestion (Ikeda and Motoda, 1978).

12 Mean abundance of *C. glacialis* C5 was 2176  $\text{ind. m}^{-2}$  during this study period.

13 C:Chl ratio was 29.9 for September in this region (Sherr et al., 2003).

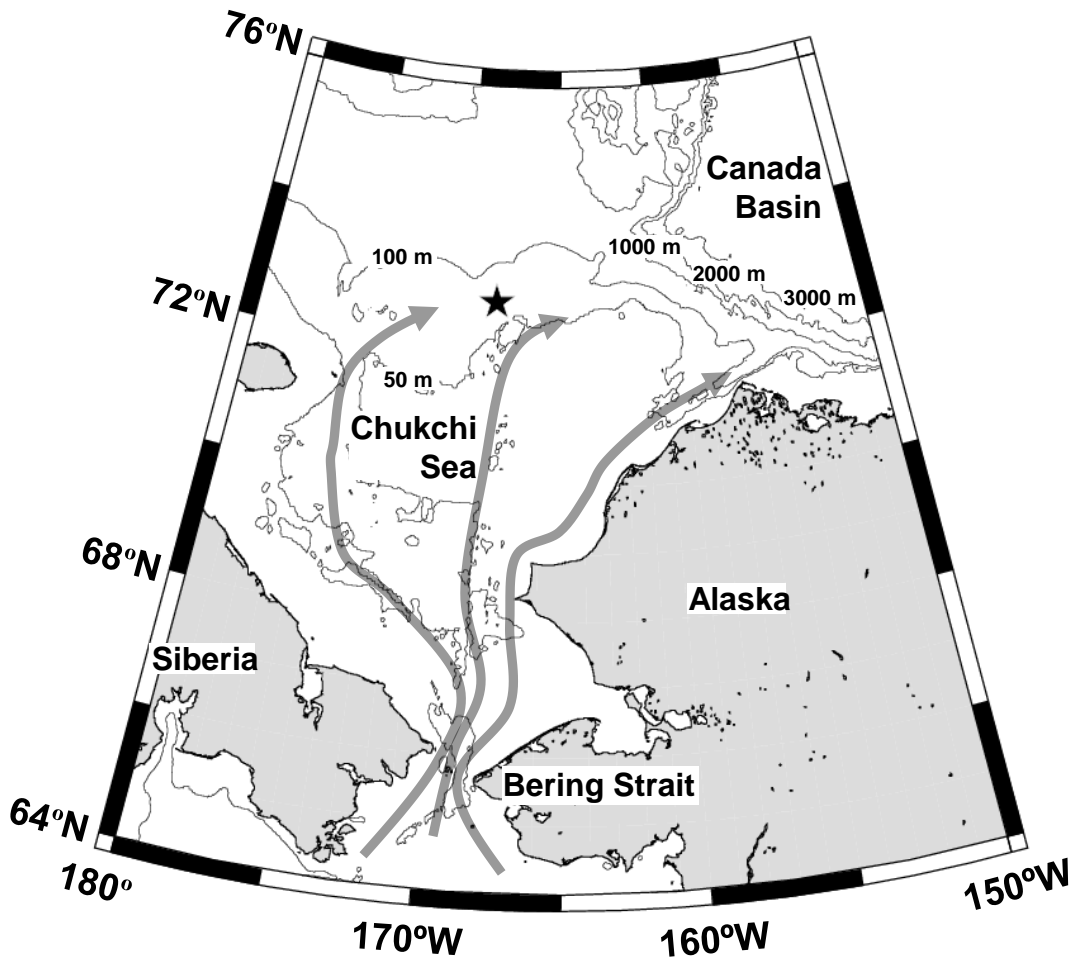


Fig. 1. (Matsuno et al.)

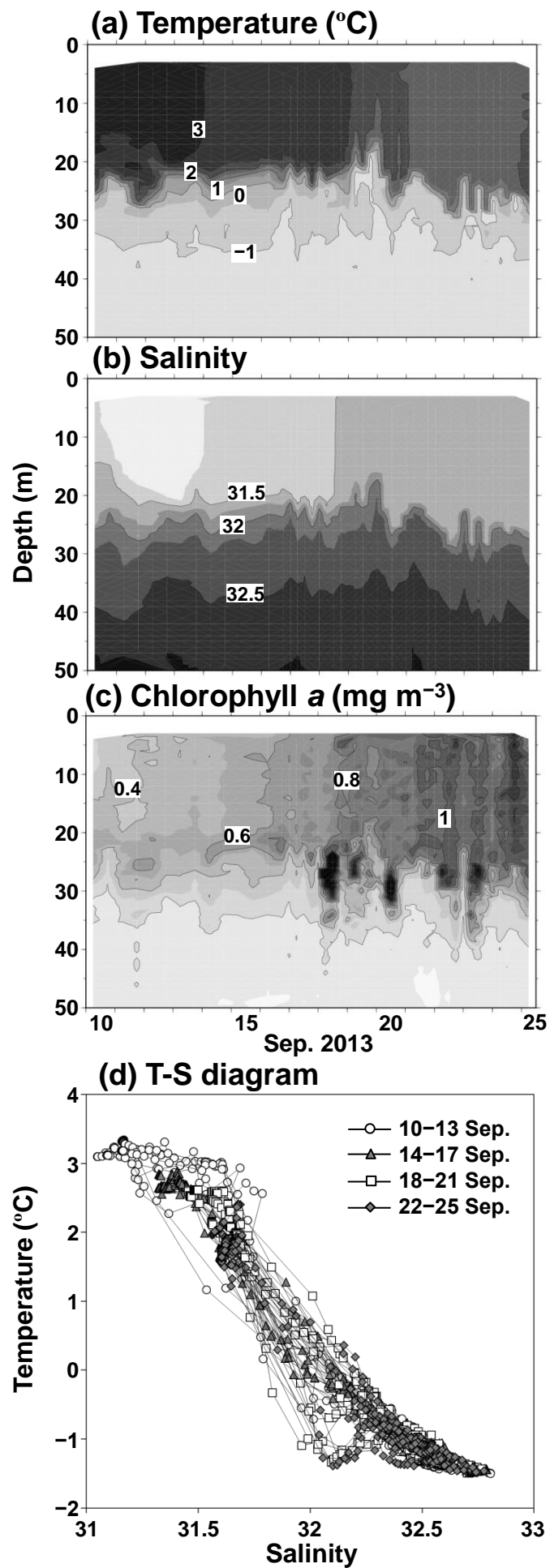


Fig. 2. (Matsuno et al.)

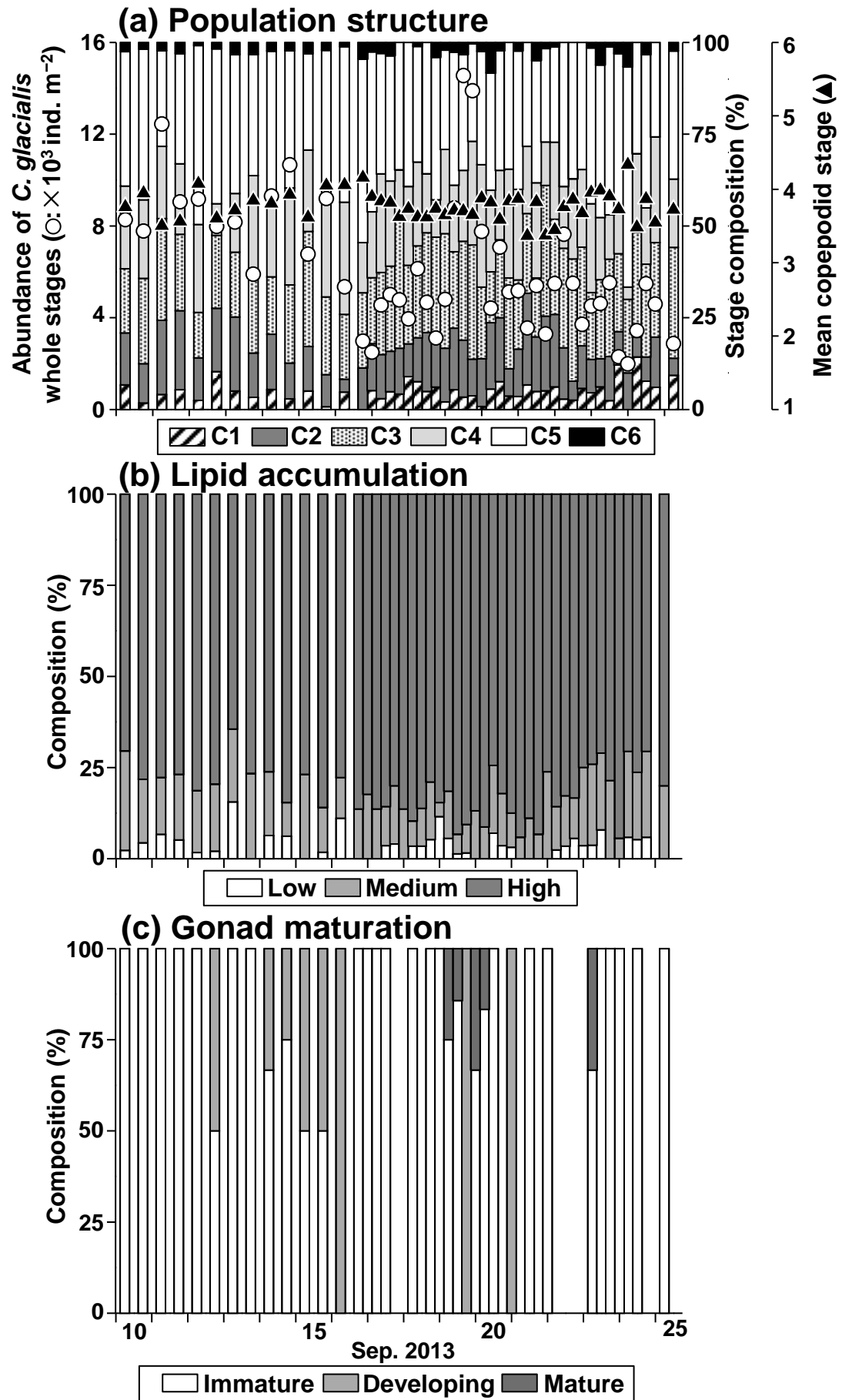


Fig. 3 (Matsuno et al.)

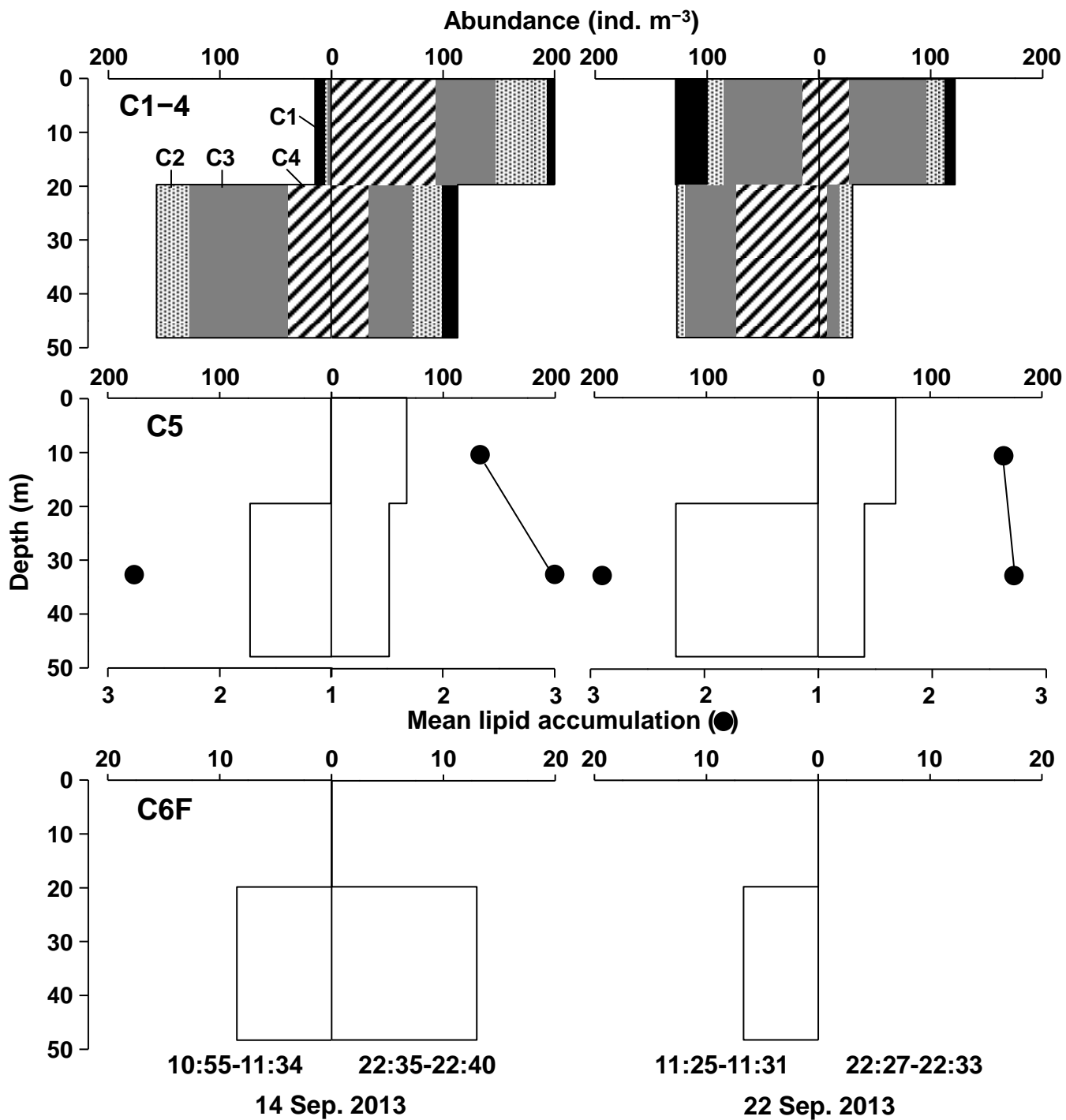


Fig. 4. (Matsuno et al.)



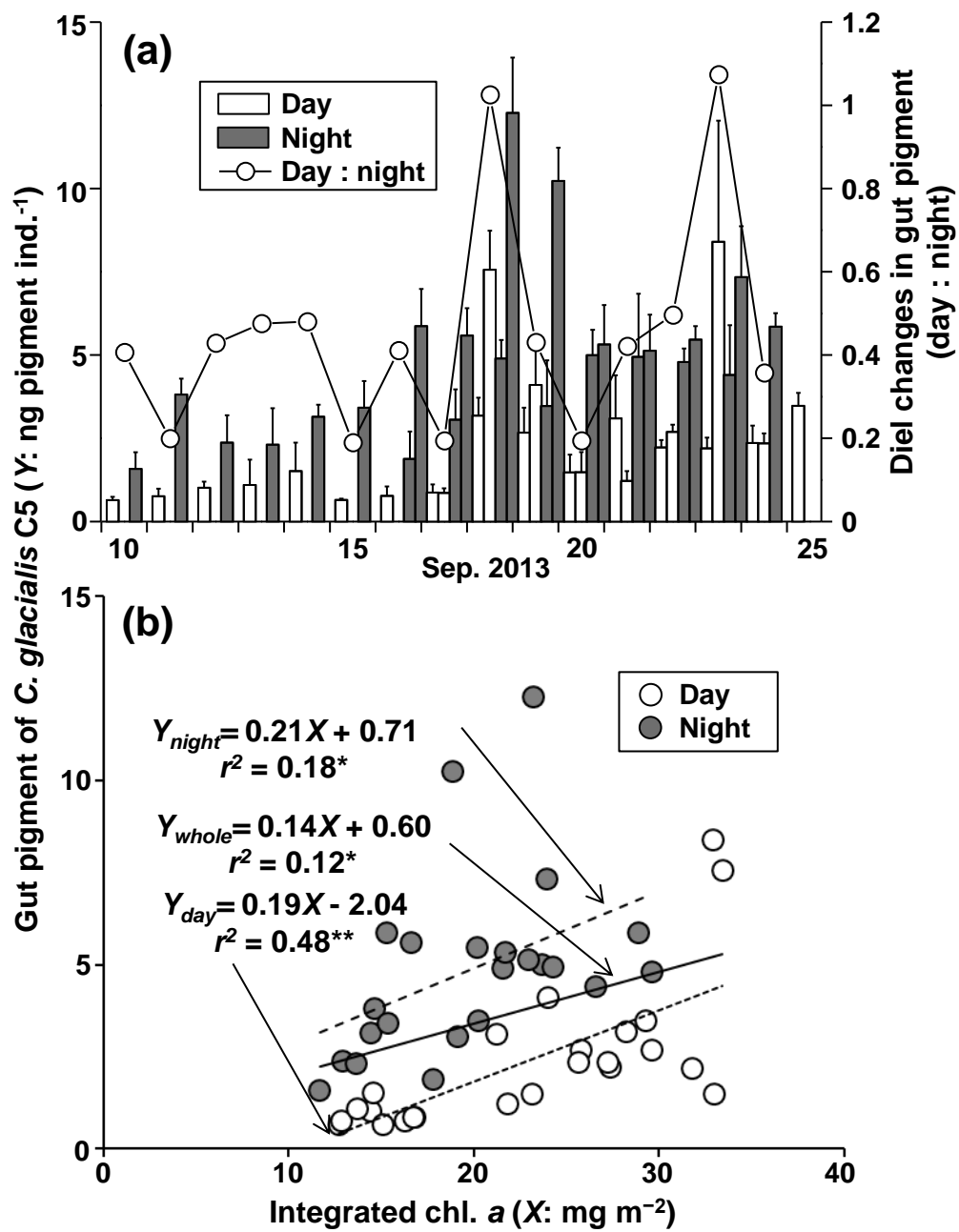


Fig. 5. (Matsuno et al.)

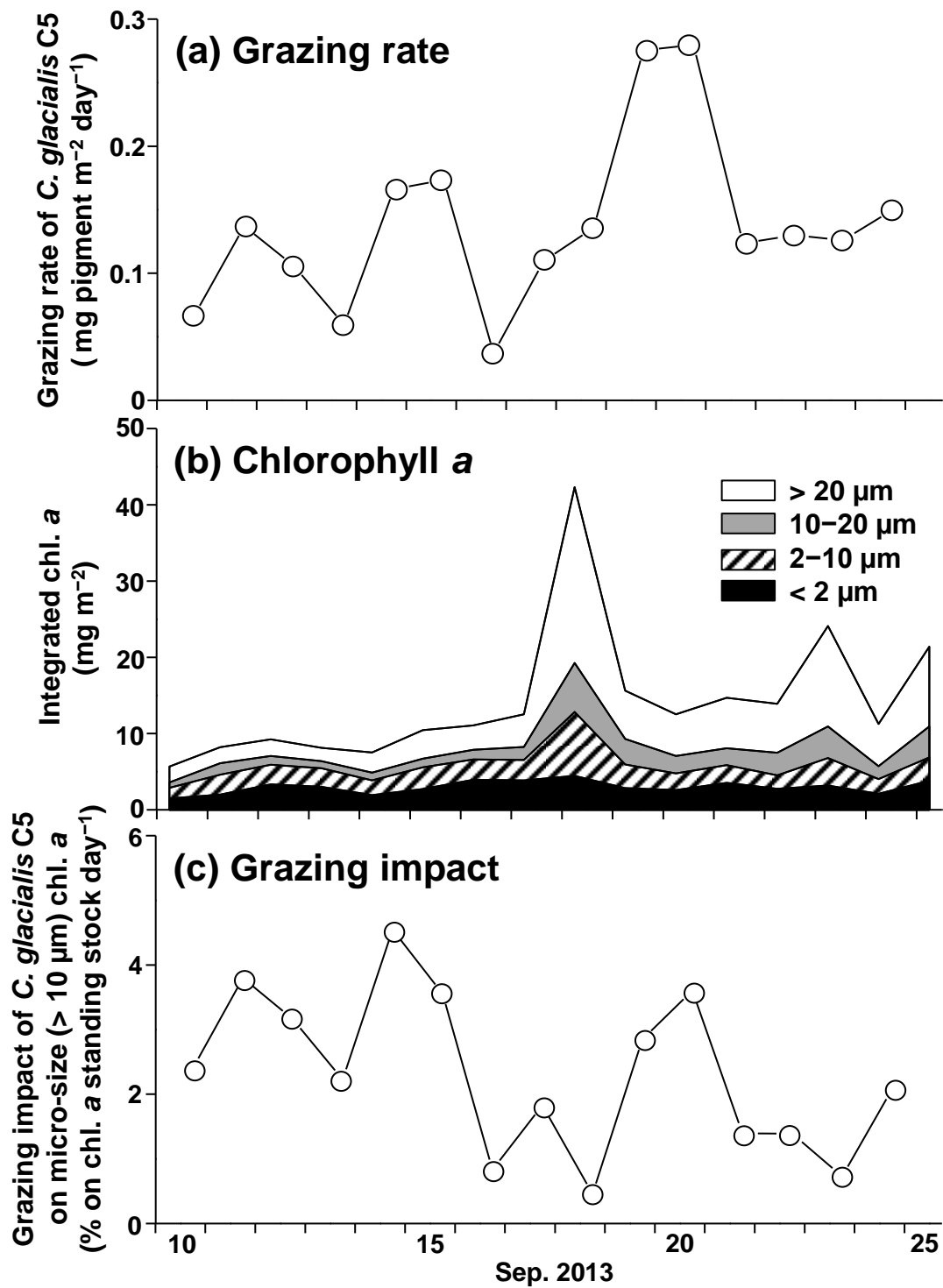


Fig. 6. (Matsuno et al.)