Author’s response to editor’s comments

We are grateful for your comments and useful suggestions, which have greatly improved our manuscript. As described below, we have revised our manuscript. Please note that the comments in black type are those provided by you, whereas those in red are our replies.

As a reviewer pointed out, English need to be improved.

Reply: We have corrected the English using a language editing service.

‘Standing stock’ should be ‘biomass’.

Reply: We changed ‘standing stock’ to ‘biomass’ throughout the manuscript (p1 L20, p2 L3, p5 L4, 7, p7 L15, p8 L3, 10, p10 L24, p18 L14).

The authors need to show more detail about the SWE in methods or discussion section, since Strong Wind Event (SWE) is a key factor for this study. Strong wind event? Based on Nishino et al. (2015), “stronger wind events” in wind speed occurred on 14thand 20thrather than 18th.How strong? Wind speed? Wind direction? Etc...Assumption on periods before SWE (10-18) and after SWE (19-25) is reasonable?

Reply: According to Kawaguchi et al. (2015), the hydrography of the study period was separated by a meteorological and oceanographic period from 10 to 18 September and 19 to 26 September, which were represented as terms I and II, respectively. Term II was characterised by longer, stronger northeasterly winds that continued for several days between 19 and 22 September, with an average intensity of greater than 13 m s^{-1}. In the revised manuscript, we included a note on this subject in the methods section (p6 L9–14).

P.4 L.6-8 Describe information about storage duration for specimens under the microscope. How much underestimation on the Chl. *a* in copepod gut could happen due to the storage?

Reply: In the sorting of samples, we added soda to avoid gut passage immediately after collection. The sorting of specimens to immerse DMF was performed at a low temperature and under dim lighting within one hour. The tubes for gut pigment extraction were stored in the dark, and fluorescence measurements were performed on board after one day. Because of these well-controlled conditions, we believe that the underestimation of the copepod gut pigment in this study is minimal. In the revised manuscript, we added a short note on this subject in the methods section (p4 L21–22).

P.4L22 This is a wrongequation, since GRind.is calculatedbased on total (Chl.*a*+phaeopigments) pigments (i.e., NOT based on Chl.*a*). Can authors use only Chl. *a*data instead of total pigments data?

Reply: Because phaeopigments are a form of decomposed pigments of chl. *a*, we estimated the copepod gut pigments based on the total value of pigments (chl. *a* + phaeopigments). In most studies on copepod gut pigments, feeding quantification by total pigments (chl. *a* + phaeopigments) is the commonly used method (cf. Dagg and Walser, 1987; Dagg, 1993). Because the phaeopigments in the water column consist of decomposed material, the feeding impact of copepods is commonly evaluated using only chl. *a* (Dagg and Walser, 1987; Dagg, 1993); therefore, we compared the total copepod pigments (chl. *a* + phaeopigments) and field fresh pigments (chl. *a*) in this study.

P9 L14-28 Authors need to conduct more careful discussion on DVM. Results, itself, only show the difference of vertical distribution between day and night time samplings. These change might be due to changing of the water mass (i.e., effects of horizontal advection, since authors clearly mentioned horizontal advection should be considered on the zooplankton distribution)? To evaluate on actuality of authors' 'guess', need more discussion based on own data and citations.

Reply: To reduce the effect of the horizontal advection of the water mass, which is primarily caused by tidal oscillation (cf. Kawaguchi et al., 2015), the day and night sampling times were set at 12-hour intervals (day: 10:55−11:34, night: 22:27−22:40). Concerning the CTD data during the two sampling dates (14 and 22 Sep.), the temperature and salinity were also presented as supplemental material (p4 L2–7, supplement). From the data, we confirmed that the hydrography exhibited tidal oscillations during the day, whereas the data from the day and night sampling periods were similar. While a slight horizontal advection effect may be present for the copepod community, we confirmed that there was little effect on the temporal changes in the copepod community (Fig. 3a). These facts suggest that the effect of the horizontal advection of the water mass on the copepod community would be minimal. In the revised manuscript, we added short notes in the methods and supplement material sections (p4 L2–7, supplement).

P9 L16 It is not easy to find only from figure 4. How we can identify the difference between migrated stages and non-migrated stages? Authors need to show a quantitative standards for judging.

Reply: Yes, this was our mistake. Regarding the comment, we performed a statistical test to evaluate the DVM (*U*-test on abundance). As a result, C3 and C4 had no day-night differences (p = 0.569 and 0.261, respectively), whereas the difference in C5 was significant ($p < 0.01$). In the revised manuscript, we updated the results (p10 L6–7).

P.10 L23 Is this (14.3 mg) low? It is two orders of magnitude higher than grazing rate of *C. glacialis*C5 (4.14/29.9 mg).

Reply: The editor's comment might be incorrect. The C:Chl. *a* ratio is 29.9 and the feeding rate in mg C m^{-2} day^{-1} is 4.14. We deleted the discussion on the grazing impact and concentrated only on the phytoplankton food composition (p11 L14–18).

P.11 L1-5 Total abundance in cell number of dinoflagellates and ciliates are <50% of the diatoms. The contribution in terms of carbon should be much smaller, since cell volumes of dinoflagellates and ciliates could be one-two orders of magnitude lower than those of phytoplankton (diatoms). Moreover, the dinoflagellates might include phytoplankton species. Thus, microzooplankton (a part of dinoflagellates and ciliates) is less important as a food sources for *C. glacialis*??? *C. glacialis* need other food resources to sustain their metabolism in the autumn.

Reply: Yes, we agree with the editor's comment. Because most of the C5 stage contained large lipids, they might be entering diapause during the study period. In the revised manuscript, we added a short note (p11 L29 – p12 L2).

P.11L6 16-18 ‘Some zooplankton’ should be *Calanus glacialis*. Put ‘a’ in front of ‘benefit’.

Reply: We changed ‘some zooplankton’ to ‘*C. glacialis*’ and added ‘a’ in front of ‘benefit’ (p12 L15).

Table 1. I would like to see standard deviations for abundance data. Also, show ‘*n*’ in the table.

Reply: We added the standard deviations and sample number (p19–20).

Figure 3 caption ‘Temporal changes in the ... gonad maturation of C6F (c) of *Calanus glacialis*...’ could be better

Reply: We changed the caption in response to this comment (p18 L6–7).

Figure 5 caption ‘Temporal and diel changes in the gut pigment of *Calanus glacialis* C5 (a) and the relationship between the gut pigment of C5 and chlorophyll *a* biomass (b) at a fixed station.... Dotted and dashed.... The whole regression line is drawn with all data from both day and night in panel b.

Reply: We changed the caption in response to this comment (p18 L12–19).

Short-term changes of the mesozooplankton community and copepod gut pigment in the Chukchi Sea in autumn: Reflections of a strong wind event

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Abstract

To evaluate the effect of atmospheric turbulence on ~~the~~ a marine ecosystem, high-frequency samplings (two to four times per day) ~~on the~~of a mesozooplankton community and the gut pigment of dominant copepods were ~~made~~ performed at a fixed station in the Chukchi Sea from 10 to 25 September 2013. During the study period, a strong wind event (SWE) was observed on 18 September. After the SWE, the biomass~~standing stock~~ of chlorophyll *a* (chl. *a*) ~~was~~ increased, especially for micro-size (> 10 µm) fractions. The z~~Z~~ooplankton abundance ranged from 23610 to 56809 ind. m^{-2} and exhibited no clear changes ~~with~~ as a result of the SWE. In terms of abundance, calanoid copepods constituted the dominant taxa (mean: 57%), followed by barnacle larvae (31%). Within the calanoid copepods, small-sized *Pseudocalanus* spp. (65%) and large-sized *Calanus glacialis* (30%) dominated. In the population structure of *C. glacialis*, copepodid stage 5 (C5) dominated, and the mean copepodid stage did not vary with the SWE. The dominance of accumulated lipids in C5 and C6 females with immature gonads indicated that they were preparing for seasonal diapause. The gut pigment of *C. glacialis* C5 was higher at night and was correlated with ambient chl. *a*, and a significant increase was observed after the SWE (2.6 vs. 4.5 ng pigment ind.$^{-1}$). The grazing impact by *C. glacialis* C5 was estimated to be 4.14 mg C m^{-2} day^{-1}, which corresponded to 0.5−4.6% of the biomass~~standing stock~~ of the micro-size phytoplankton. Compared with the metabolic food requirement, *C. glacialis* ~~their~~ feeding on phytoplankton accounted for 12.6% of their total food requirement. These facts suggest that *C. glacialis* could not maintain their population ~~on~~ by feeding solely on phytoplankton~~ food,~~ and that other food sources (i.e., microzooplankton) ~~are~~ must be important in autumn. As observed ~~for~~ by the increase in gut pigment, the temporal phytoplankton bloom, which is enhanced by the atmospheric turbulence (SWE) in autumn, may have a positive effect on copepod nutrition.

1 Introduction

In marine ecosystems of the western Arctic Ocean, mesozooplankton is an important food resource for pelagic fishes and whales (Lowry et al., 2004; Ashjian et al., 2010). In terms of biomass, mesozooplankton in the western Arctic Ocean ~~is~~ are dominated by Arctic copepods. Within ~~the~~ Arctic copepods, *Calanus glacialis* is a key species that dominates ~~in~~ the zooplankton biomass and commonly occurs in the continental shelf throughout the Arctic Ocean (Conover and Huntley, 1991; Lane et al., 2008). ~~For t~~The life cycle of *C. glacialis* is characterized by their growth~~, they grow~~ to C3−C4 at the epipelagic layer during the first summer; t~~, t~~hen, they descend to ~~the~~ a deeper layer and enter diapause, developing to C5 at the epipelagic layer in the second summer before descending~~, then~~ down to ~~the~~ a deeper layer and ~~molting~~moulting to the adult stage (C6)~~,~~ ~~using~~ utilizing stored lipids ~~as~~ for energy (Longhurst et al., 1984; Ashjian et al., 2003; Falk-Petersen et al., 2009). Concerning seasonal changes, a comparison was made of the zooplankton community between summer and autumn (Llinás et al., 2009)~~,~~ and year-round changes based on ~~the~~ a two-week sampling interval at a drifting ice station in the Arctic basin ~~were reported~~ (Ashjian et al., 2003). However, short-term changes in the zooplankton community based on high-frequency samplings (two to four times per day) have not yet been reported.

Recently, a drastic reduction in the area of sea ice has been observed in the Arctic Ocean during summer; the ~~, and the~~ sea ice reduction was greatest in the western Arctic Ocean (Stroeve et al., 2007; Comiso et al., 2008; Markus et al., 2009). Furthermore, increases in the frequency and magnitude of cyclones and a northward shift of their tracks during the summer have been reported in recent years (Serreze et al., 2000; Cabe et al., 2001; Zhang et al., 2004;

Sepp and Jaagus, 2011). While the importance of such changes is clear, little information is available regarding their effect on the atmospheric turbulence in marine ecosystems in the western Arctic Ocean. From 10 to 25 September 2013, high-frequency samplings/observations ~~was~~ were made at a fixed station in the Chukchi Sea~~,~~ and the occurrence of strong wind events (SWE), a vertical flux of nutrients and changes in the primary production and microplankton communities were reported (Nishino et al., 2015; Yokoi et al., submitted). However, no information is available regarding how the mesozooplankton community responds to such atmospheric turbulence and oceanic environmental changes.

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

2 Materials and Methods

2.1 Field sampling

Zooplankton samplings were ~~conducted~~ obtained at a fixed station in the Chukchi Sea (72°45´N, 168°15´W, depth 56 m) from 10 to 25 September 2013 (Fig. 1) (Nishino et al., 2015). Zooplankton samples were collected by vertical hauls with a NORPAC net (mouth diameter 45 cm, mesh size 335 µm; Motoda, 1957) and ring net (mouth diameter 80 cm, mesh size 335 µm) from a 49 m depth to the sea surface two to four times per day (total of 47 times), including both day and night. The large mesh size of the NORPAC net (335 µm) may ~~induce somewhat~~~~result~~have resulted in a slight underestimation of the smaller zooplankton species and early stages of larger zooplankton species. Zooplankton samples collected ~~by~~ with the NORPAC nets were preserved with 5% buffered formalin immediately after being brought on board. The ring net samples were used for copepod gut pigment measurements. For the evaluation of the diel vertical migration (DVM) of the copepods, day and night vertical stratified hauls were taken with closing PCP nets (mouth diameter 45 cm, mesh size 62 µm; Kawamura, 1989) from two layers (0−20 m and 20−49 m) ~~were made~~ on 14 and 22

September. The samples from the PCP net were preserved with 5% buffered formalin. During the sampling period, there was a horizontal advection of the water mass oscillation caused by tidal waves~~ is reported~~ (Kawaguchi et al., 2015). To minimi~~zs~~ze the effect of the tidal oscillation, ~~we set~~ day and night sampling times ~~with~~were set at 12-hour intervals (day: 10:55−11:34, night: 22:27−22:40). The four-time CTD casts at each sampling date confirmed that the hydrography was similar for the day-night sampling period (the CTD data are presented as supplemental material). ~~The samples from the PCP net were preserved with 5% buffered formalin.~~

At the fixed station, the temperature, salinity and chlorophyll *a* (chl. *a*) fluorescence were measured using the~~by~~ CTD (Sea-Bird Electronics Inc., SBE911Plus) casts at a frequency of two to four times per day. To evaluate the size~~-~~fractionated chl. *a*, water samples from the sea surface and the maximum fluorescence layer (16.8−27.7 m depth) were collected ~~by~~ using a bucket and rosette multi-sampler mounted on the CTD, respectively. ~~Water~~ The water samples were filtered through 20, 10 and 2-μm pore-size membranes and GF/F filters, and chl. *a* was extracted with N,N-dimethylformamide and measured with a fluorometer (Turner Designs, Inc., 10-AU-005).

2.2 Gut pigment

For fresh samples collected ~~by~~ using ring nets, 10% v/v soda (saturated CO_2 in water) was added to avoid copepod grazing, gut evacuation and the decomposition of gut pigments. Fresh specimens of *C. glacialis* copepodid stage 5 (C5) were sorted under a stereomicroscope. The sorting of a~~A~~ll of the ~~sortings~~specimens was performed~~ were made~~ under low temperatures and dim light conditions within ~~an~~one hour. Batches of fifteen specimens were immersed in 6 ml of N,N-dimethylformamide and stored in dark, cold conditions overnight to extract the chlorophyll and phaeopigments. After the extraction of the pigment, the chlorophyll and phaeopigments were measured ~~with~~ using a fluorometer (Turner Designs, Inc., 10-AU-005). The c~~C~~hlorophyll and phaeopigments were summed and expressed as gut pigments (ng pigment ind.$^{-1}$) (cf. Mackas and Bohrer, 1976).

The amount gut pigment of *C. glacialis* C5 was higher at night~~time~~ than during the day~~time~~. Assuming that ~~their~~ grazing primarily ~~at~~ occurred at night, the grazing rate ($GR_{ind.}$, mg pigment ind.$^{-1}$ day^{-1}) of *C. glacialis* C5 was calculated using the ~~from~~ following equation:

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

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

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

where N is the abundance of *C. glacialis* C5 (ind. m^{-2})~~,~~ and *Int. chl. a* is the biomass~~standing stock~~ of large-sized (> 10 µm) chl. *a* (mg m^{-2}).

2.3 Zooplankton community

In the ~~land~~ laboratory, identification and enumeration by taxa were performed on zooplankton samples collected ~~by~~ using NORPAC nets under a stereomicroscope. For the dominant taxa (calanoid copepods), identification was ~~made~~ performed ~~to~~ at the species and copepodid stage levels. For species identification of calanoid copepods, we referred ~~mainly~~ mostly to Brodsky (1967) and Frost (1974) for *Calanus* spp., Miller (1988) for *Neocalanus* spp. and Frost (1989) for *Pseudocalanus* spp. For *Pseudocalanus* spp., species identification was ~~made~~ performed only for late copepodid stage C5 females/males (C5F/M) and C6F/M, and their early copepodid stages (C1−C4) were treated as *Pseudocalanus* spp.

For the evaluation of the DVM of large dominant copepods, we enumerated *C. glacialis* from PCP net samples. For *C. glacialis*, the lipid accumulation of C5 was ~~scored~~classified into three categories: I (the oil droplet length (ODL) was 0−4% of the prosome length (PL)), II (ODL was 4−40% of PL) and III (ODL was > 40% of PL). The g~~G~~onad maturation of *C. glacialis* C6F was also ~~scored~~ classified into three categories: I (immature), II (small oocytes in the ovary or oviduct) and III (large eggs or distended, opaque, filled-in oviducts). For this gonad maturation index, we cited ~~those~~ that ~~for~~ of *C. hyperboreus* (Hirche and Niehoff, 1996).

A species diversity index (*H*´) in each sample was calculated using the equation:

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

where n is the abundance (ind. m^{-2}) of the *ith* species and Ni is the abundance (ind. m^{-2}) of the total calanoid copepods in the sample (Shannon and Weaver, 1949). Pielou evenness (*J*´) was also calculated using the equation:

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

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

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

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

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

During the study period, a SWE was observed ~~aroungfrom~~on approximately 19~~18~~ to 22~~19~~ September (Kawaguchi et al., 2015; Nishino et al., 2015). ~~Owing~~According to Kawaguchi et al. (2015), ~~the~~there were meteorologically and oceanographically distinct periods between 10 and ~~−~~18 September and~~,~~ 19 and ~~−~~26 September, represented as terms I and II, respectively. Term II was characteri~~z~~sed by longer, stronger northeasterly winds, which continued for several days between 19 and 22 September,~~ and~~ ~~whose~~the average intensity of which was greater than 13 m s^{-1}. To evaluate the effect of the SWE, the abundances of each zooplankton taxon and species were compared ~~between~~ “before the SWE (10−18 September)” and “after the SWE (19−25 September)” using the *U*-test. This statistical analysis was performed ~~with~~ using Stat View.

書式変更: 英語（英国）, 上付き

3 Results

3.1 Hydrography and chlorophyll *a*

During the sampling period, the temperature ranged from -~~−~~1.5~~ºC~~ to 3.3ºC~~,~~ and a thermocline was observed at a depth of approximately 25 m (Fig. 2a). Cold water below 0ºC continuously ~~occurred~~ persisted below the thermocline, whereas the temperature above the thermocline decreased from 3.3 to 1.5ºC during the study period (Fig. 2a). The s~~S~~alinity ranged from 31.1 to 32.8, and a halocline was observed at approximately 25 m, which ~~was~~ ran parallel to the thermocline (Fig. 2b). The s~~S~~alinity below the halocline was constant (ca. > 32), whereas the salinity in the upper layer increased from 31.1 to 31.6 throughout the study period. Chl. *a* ranged from 0.08 to 3.25 mg m^{-3} and increased after the SWE (Fig. 2c). The T-S diagram showed that the hydrographic conditions in the upper layer changed temporally; thus, the temperature decreased, ~~while~~whereas the salinity increased during the study period (Fig. 2d).

3.2 Zooplankton community

The z~~Z~~ooplankton abundance ranged from 23610 to 56809 ind. m^{-2}, and the calanoid copepods and barnacle larvae composed 57% and 31% of the community, respectively (Table 1). For the calanoid copepods, 15 species belonging to nine genera were identified. ~~Within~~ Among them, *Pseudocalanus* spp. and *C. glacialis* dominated and composed 65% and 30% of the total copepods, respectively. The s~~S~~hannon species diversity and Pielou evenness for the copepods ~~commuity~~community were 1.87±0.12 and 0.81±0.06, respectively. According to a comparison of time periods before and after the SWE, the total zooplankton abundance, the Shannon species diversity and the Pielou evenness did not change, whereas one calanoid copepod, *Centropages abdominalis*, and the cyclopoid copepods increased after the SWE (Table 1). ~~On the other hand~~However, one calanoid copepod, *Metridia pacifica*;~~,~~ appendicularians;~~,~~ barnacle larvae~~,~~; euphausiids; and gymnosomes (*Clione limacina*) decreased after the SWE.

3.3 *Calanus glacialis*

Throughout the study period, the ~~standing stock~~biomass of *C. glacialis* ranged from 1990 to 14554 ind. m^{-2}~~,~~ and no significant changes were detected ~~with~~ after the SWE (Fig. 3a, Table 1). For the population structure, all of the copepodid stages (C1 to C6F/M) ~~occurred~~were present, and C5 was the most dominant stage (36%) of the population (Fig. 3). The *MCS* did not vary with the SWE (Fig. 3a). Throughout the study period, the lipid accumulation of C5 was high (Fig. 3b)~~,~~ and the gonad maturation of C6F was dominated by immature specimens (Fig. 3c). These parameters exhibited no significant changes with regard to the SWE (*U*-test, $p = 0.285–0.303$).

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

The gut pigment of *C. glacialis* C5 ranged from 0.6 to 12.3 ng pigment ind.$^{-1}$ and showed a significant increase after the SWE (mean values: 2.6 vs. 4.5 ng pigment ind.$^{-1}$, *U*-test, $p < 0.01$) (Fig. 5a). In a comparison between day and night samplings, most dates, except 18 and 23 September, ~~showed~~ exhibited higher gut pigment levels at night by a factor of two to five times greater than those ~~of the~~observed during the day~~time~~. In both day and night samplings, the gut pigments were correlated with ~~a~~ the biomass~~standing stock~~ of chl. *a* ($p < 0.05$) (Fig. 5b).

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

4 Discussion

4.1 Zooplankton community

The zooplankton community in the Chukchi Sea is known to have large spatial and temporal changes (Springer et al., 1989; Llinás et al., 2009; Matsuno et al., 2011). The t~~T~~otal zooplankton abundance in this study was approximately half (mean: 34059 ind. m^{-2}) the abundance reported by Matsuno et al. (2012) on the Chukchi shelf (mean: 75683 ind. m^{-2}), with a low abundance of small copepods (*Pseudocalanus* spp. and cyclopoids) and ~~the~~ a remarkable absence of the Arctic copepod *Metridia longa*. For the hydrography of this station, Nishino et al. (2015) noted that the upper, warm and less-~~–~~saline water was the Pacific s~~S~~ummer water, which was transported to the Arctic Ocean during summer, and the cold saline water of the lower layer was the remnant brine of the Pacific w~~W~~inter water, which was transported to the Arctic Ocean during winter. Geographically, the present station ~~was~~ is located at a ~~main~~ primary stream of water from the ~~the~~ Pacific~~’s~~ ~~waters~~ Ocean (Weingartner et al., 2005). The high abundance of the Pacific copepod *M. pacifica* and *Neocalanus* spp.~~,~~ and the ~~lack~~ absence of the ~~occurrence of the~~ Arctic *M. longa* in this study was thought to be a reflection of the water mass covering the station. ~~Because of~~For these reasons (less small copepods and high abundance of Pacific copepods), the Shannon species diversity and Pielou evenness in this study (1.87 and 0.81, respectively) are higher than the reported values for the ~~whole~~ entire Chukchi Sea (1.79 and 0.62, respectively, calculated from Matsuno et al., 2012).

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

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

4.2 Population structure of *C. glacialis*

Concerning the population structure, Ashjian et al. (2003) reported that *C. glacialis* around the Northwind Abyssal Plain was dominated by C5 and C6F in September. In the present study, the population structure of *C. glacialis* was dominated by C5 (Fig. 3a)~~,~~ and their *MCS* (mean±sd: 3.77±0.20) was similar to the reported value for autumn in this region (3.58, Matsuno et al., 2012). Most of the C6F had immature gonads, and no ovigerous C6Fs were observed (Fig. 3c). These results corresponded with the year-round observation around the Northwind Abyssal Plain (Ashjian et al., 2003). *Calanus glacialis* C6F is known to occur at the epipelagic layer in April, ~~just~~ immediately before sea-ice melting (Kosobokova, 1999), and ~~to~~ reproduces with grazing ice algae and the ice-edge bloom (Campbell et al., 2009).

Thus, because this study period (September) greatly varied with regards to their reproduction period (April), most C6Fs were considered to have immature gonads when residing in the lower layer (diapause).

The n~~N~~octurnal ascent DVM, which is related to night-time grazing on phytoplankton, was reported for *C. glacialis* in the Arctic Ocean during spring and autumn (Runge and Ingram, 1988; Conover and Huntley, 1991). In this study, the DVM was observed for ~~C3, C4 and~~ C5 (*U*-test, $p < 0.01$) (Fig. 4). At high-latitude seas, the magnitude of the *Calanus* spp. DVM is known to vary with the season and copepodid stage, and their DVM intensity is greater during spring and autumn when the diel changes in light penetration are large (Falkenhaug et al., 1997). No DVM of *Calanus* spp. was reported for the lipids accumulated in C5 (Falk-Petersen et al., 2008). In the present study, ~~nearly~~approximately half of the C5 population, which was characteri~~zs~~zed as having a large lipid accumulation, remained in the lower layer throughout the day (Fig. 4). The deep C5 population may have already completed lipid accumulation and ceased DVM in the study period (September), ~~while~~whereas the remaining C5 population with an active DVM may have grazed on phytoplankton in the upper layer during the night and stored lipids in preparation for diapause. These results suggest that the *C. glacialis* population in this study was at the seasonal phase just before entering diapause, and this interpretation corresponded well with their life cycle in this region (Ashjian et al., 2003).

4.3 Grazing of *C. glacialis*

The ~~gut pigment~~ of *C. glacialis* in the Arctic Ocean is known to exhibit diel changes and higher gut pigment levels at night than ~~in~~ during the day~~time~~ (Conover and Huntley, 1991). Higher gut pigment levels at night were also observed in this study (*U*-test, $p < 0.001$) (Fig. 5a). ~~Their~~ The gut pigments of *C. glacialis* were correlated with the biomass~~standing stock~~ of chl. *a* (Fig. 5b) and increased~~, and increasinged~~ during the high chl. *a* period after the SWE (Fig. 5a). These facts suggest that *C. glacialis* feeding responded to the small phytoplankton bloom, which was enhanced by the nutrient supply and vertical mixing caused by the SWE (Nishino et al., 2015; Yokoi et al., submitted).

Concerning the gut pigment measurement, the underestimation by the decomposition of the phytoplankton pigment through the gut passage has been reported (Conover et al., 1986; Head, 1992). This underestimation is reported to be ~~ca.approximatley~~approximately 0.1−10% of grazing (Conover et al., 1986) and varies with light conditions, grazing

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~~behavior~~behaviour and phytoplankton species (Head, 1992). To estimate the grazing impact, data on the gut evacuation rate (*k*, min^{-1}) ~~is~~ are needed (Mauchline, 1998). The gut evacuation rate is known to have a positive correlation with temperature (Dam and Petersen, 1988). From the equation ~~between~~ for *k* and the temperature (T: ºC): $k = 0.00941+0.002575T$ (Mauchline, 1998) and ambient temperature in this study (T: ~~-~~−1.5 to 3.3ºC), *k* ~~would be~~is estimated to be 0.0055−0.0179 min^{-1}. This range covers the value applied in the present study ($k = 0.017$, Tande and Båmstedt, 1985). The value was also ~~at~~ in the range observed by our independent laboratory experiments in September 2010 (0.006−0.041, Matsuno et al., unpublished data). These facts suggest that the value applied in this study ($k = 0.017$) was reasonable for *C. glacialis* in this region.

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

We also estimated the food requirement of *C. glacialis* C5 to support their metabolism under ambient temperatures (Ikeda and Motoda, 1978; Ikeda et al., 2001). The potential contribution of phytoplankton's food~~-~~to~~-~~food requirements was 12.6% for *C. glacialis* C5 (Table 2). This result indicates that *C. glacialis* C5 could not maintain its population solely on phytoplankton food and that~~;~~ other food sources are important. Regarding food for *C. glacialis*, Campbell et al. (2009) reported that this species prefers microzooplankton rather than phytoplankton in the Chukchi Sea, and Levinsen et al. (2000) noted that the micro-size (> 10 μm) ciliates and dinoflagellates are important food sources during post-bloom. For the microplankton community during the study period, Yokoi et al. (submitted) noted that not only diatoms (1.64−14.11 cells ml^{-1})~~, but also~~ but also dinoflagellates (0.54−2.42 cells ml^{-1}) and ciliates (0.14−2.76 cells ml^{-1}) were abundant. From the fatty acid composition, *C. glacialis* is reported to have a strong connection with the microbial food web (Stevens et al., 2004). However, the low abundance of dinoflagellates and ciliates during the study period ~~seems~~makes it difficult to assume that they were an important food source for *C. glacialis* ~~at~~in this study. As an alternative explanation, ~~since~~because most *C. glacialis* C5 contained

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~~much~~an abundance of lipids in their body (Fig. 3b), they may have entered diapause in the Chukchi Sea during autumn.~~Thus, as food sources for *C. glacialis*, microzooplankton (dinoflagellates and ciliates) are considered to be important in the Chukchi Sea during autumn.~~

5 Conclusions

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

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Author contributions

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

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Figure captions

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

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

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

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

Figure 5. ~~*Calanus glacialis*: t~~Temporal and diel changes in the gut pigment of *Calanus glacialis* C5 (a), and ~~at a fixed station in the Chukchi Sea from 10 to 25 September 2013. The~~ the relationship between the gut pigment of C5 and ~~standing stock~~ chlorophyll *a* biomass (b) at a fixed station in the Chukchi Sea from 10 to 25 September 2013. Dotted and dashed lines indicate regressions for day and night, respectively. The whole regression line is drawn with all of the data from both day and night in panel b. ~~For (b), "whole" indicates including all data, both day and night.~~ **: $p < 0.01$, *: $p < 0.05$.

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Figure 6. Temporal changes in the grazing rate of *Calanus glacialis* C5 (a), integrated size-fractionated chlorophyll *a* (b) and ~~the~~ grazing impact of *C. glacialis* C5 on micro-phytoplankton (> 10 µm) (c) at a fixed~~-~~station in the Chukchi Sea from 10 to 25 September 2013.

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

Species/taxa Population parameters	Before SWE (10−18 Sep., *n* = 22)~~Before SWE (10−18 Sep.)~~	After SWE (19−25 Sep., *n* = 25)~~After SWE (19−25 Sep.)~~	*U*-test
Calanoid copepods			
Acartia longiremis	604±281~~604~~	542±279~~542~~	NS
Calanus glacialis	6714±2679~~6714~~	5658±3061~~5658~~	NS
Calanus hyperboreus	0 ~~0~~	5±17~~5~~	NS
Centropages abdominalis	9±23~~9~~	29±38~~29~~	*
Eucalanus bungii	6±20~~6~~	6±19~~6~~	NS
Eurytemora herdmani	0 ~~0~~	2±12~~2~~	NS
Metridia pacifica	251±150~~251~~	154±139~~154~~	*
Microcalanus pygmaeus	6±19~~6~~	3±14~~3~~	NS
Neocalanus cristatus	6±19~~6~~	5±19~~5~~	NS
Neocalanus flemingeri	46±44~~46~~	65±79~~65~~	NS
Neocalanus plumchrus	12±26~~12~~	15±32~~15~~	NS
Pseudocalanus acuspes	3393±1239~~3393~~	3254±1651~~3254~~	NS
Pseudocalanus mimus	1194±728~~1194~~	1296±837~~1296~~	NS
Pseudocalanus minutus	2178±768~~2178~~	2387±864~~2387~~	NS
Pseudocalanus newmani	2805±949~~2805~~	2774±1448~~2774~~	NS
Pseudocalanus spp. (C1−C4)	2758±1114~~2758~~	2980±1196~~2980~~	NS
Cyclopoid copepods	511±263~~511~~	1153±974~~1153~~	**
Poecilostomatoid copepods	0 ~~0~~	3±14~~3~~	NS

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Amphipoda	9±24~~9~~	5±19~~5~~	NS
Appendicularia	707±413~~707~~	442±337~~442~~	*
Barnacle larva	12118±2399~~12118~~	8945±2341~~8945~~	***
Chaetognatha	1281±531~~1281~~	1039±504~~1039~~	NS
Echinodermata larva	31±45~~31~~	61±79~~61~~	NS
Eubrachyura zoea	41±60~~41~~	26±52~~26~~	NS
Euphausiacea	18±31~~18~~	3±14~~3~~	*
Gymnosomata	172±133~~172~~	84±88~~84~~	**
Hydrozoa	209±127~~209~~	205±119~~205~~	NS
Isopoda	3±14~~3~~	3±14~~3~~	NS
Polychaeta	1124±311~~1124~~	1005±435~~1005~~	NS
Thecosomata	16±43~~16~~	8±30~~8~~	NS
Total zooplankton	36223±5984~~36223~~	32154±7716~~32154~~	NS
Shannon species diversity	1.85±0.11~~1.85~~	1.90±0.11~~1.90~~	NS
Pielou evenness	0.80±0.05~~0.80~~	0.82±0.06~~0.82~~	NS

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

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

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

Oxygen consumption (μL O_2 $ind.^{-1}$ h^{-1}) = exp(-0.399+0.801×Ln(*DM*)+0.069×*T*)) (Ikeda et al., 2001).

Respiratory quotient ($[CO_2/O_2]$) was assumed to be 0.97 (Gnaiger, 1983).

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

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

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

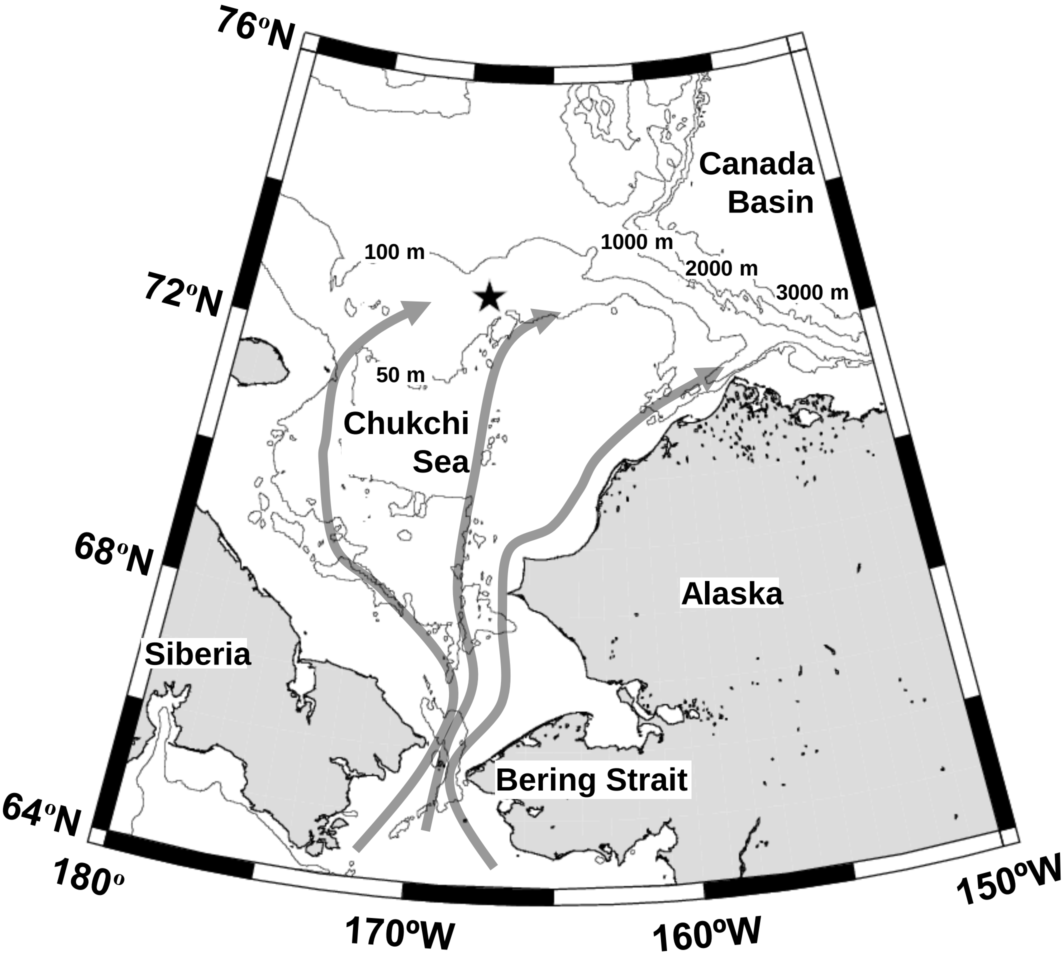
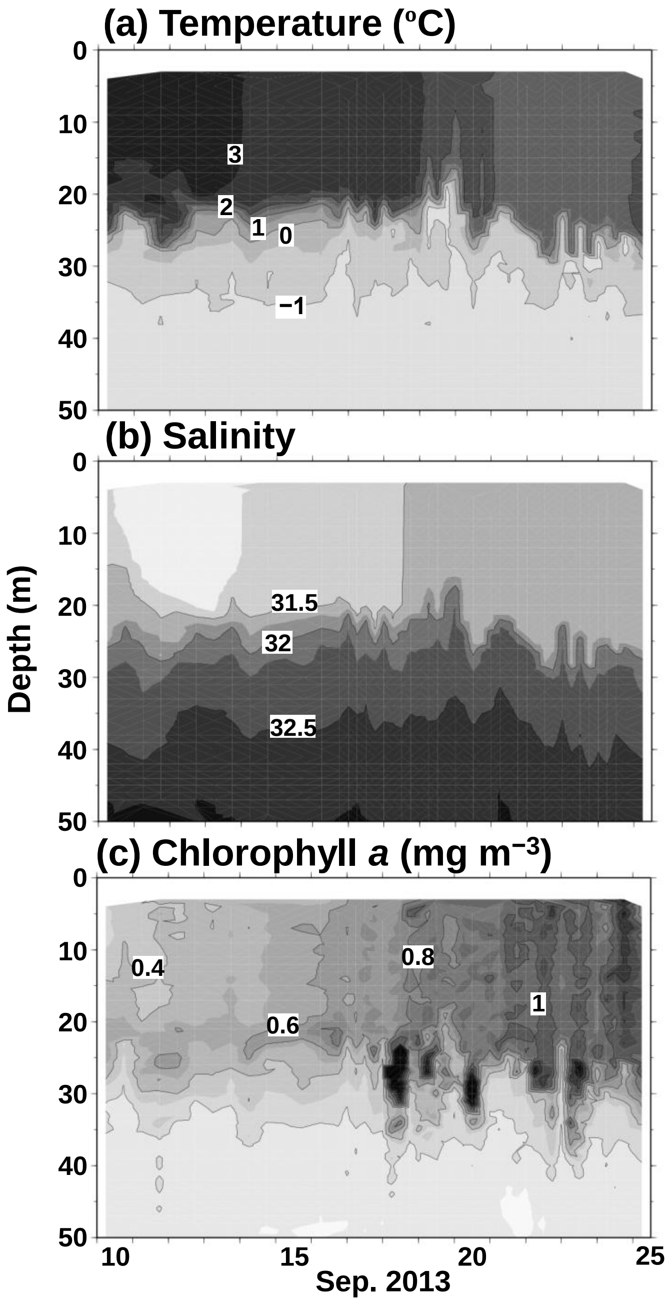


Fig. 1. (Matsuno et al.)


(a) Temperature (°C)

(b) Salinity

(c) Chlorophyll *a* (mg m^{-3})

(d) T-S diagram

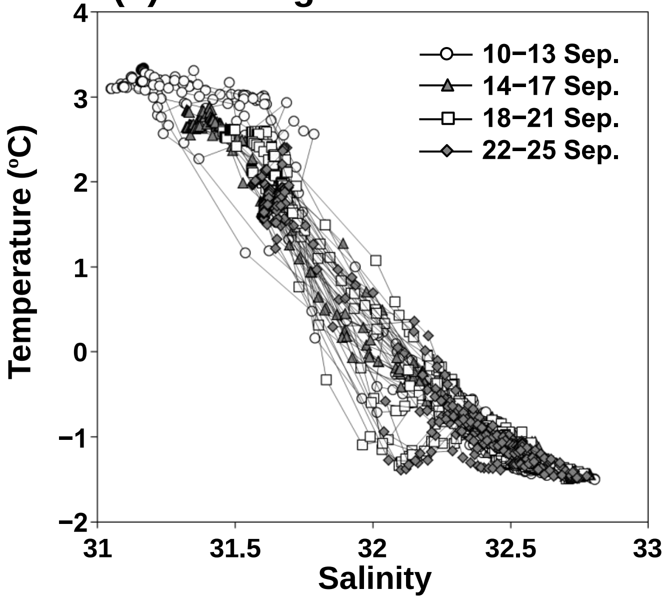
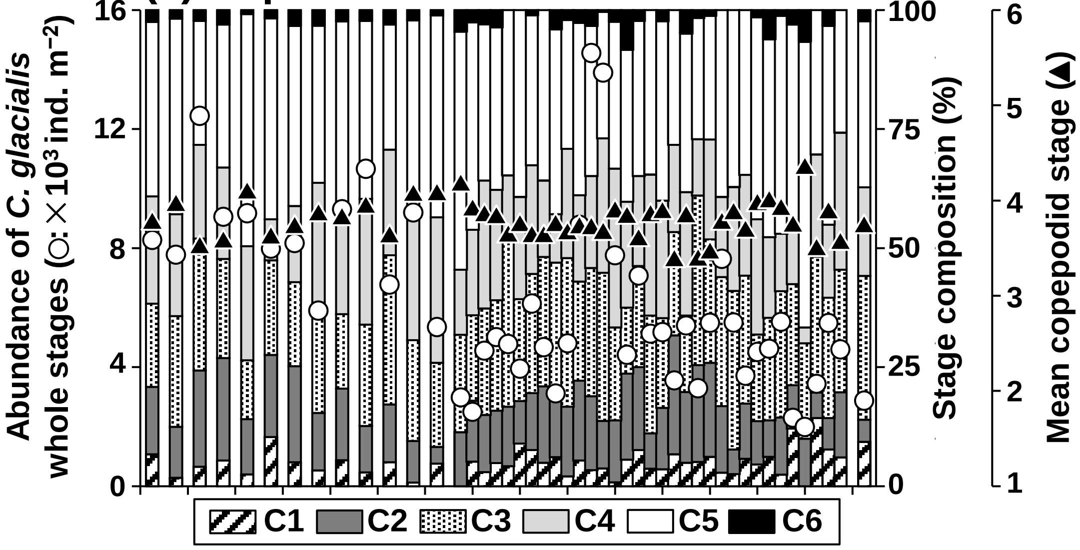
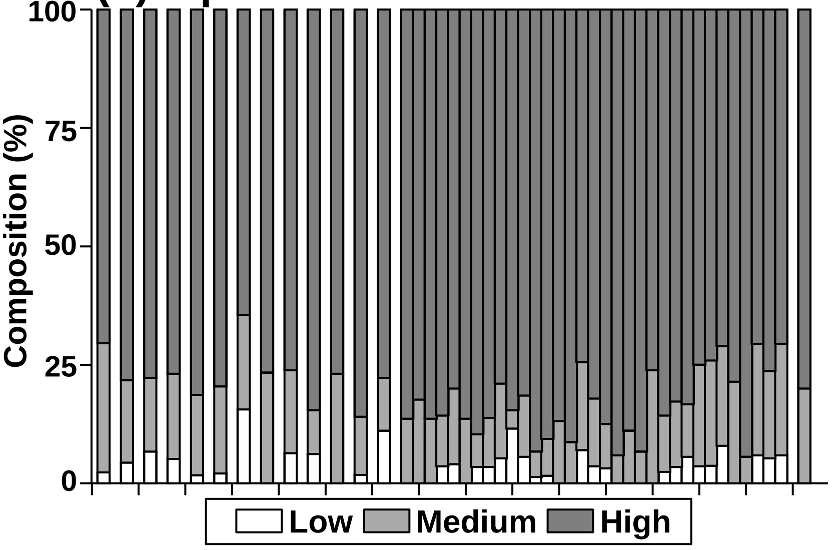


Fig. 2. (Matsuno et al.)

(a) Population structure



(b) Lipid accumulation



(c) Gonad maturation

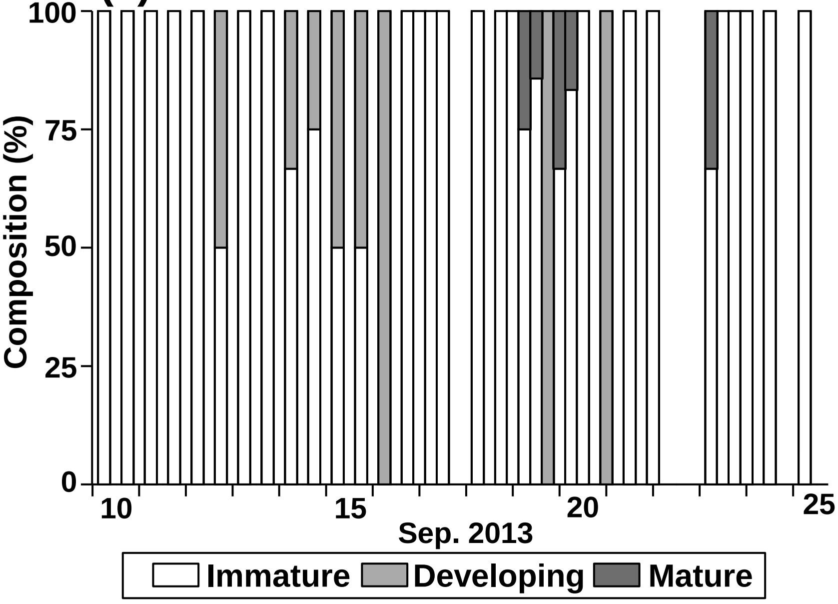


Fig. 3 (Matsuno et al.)

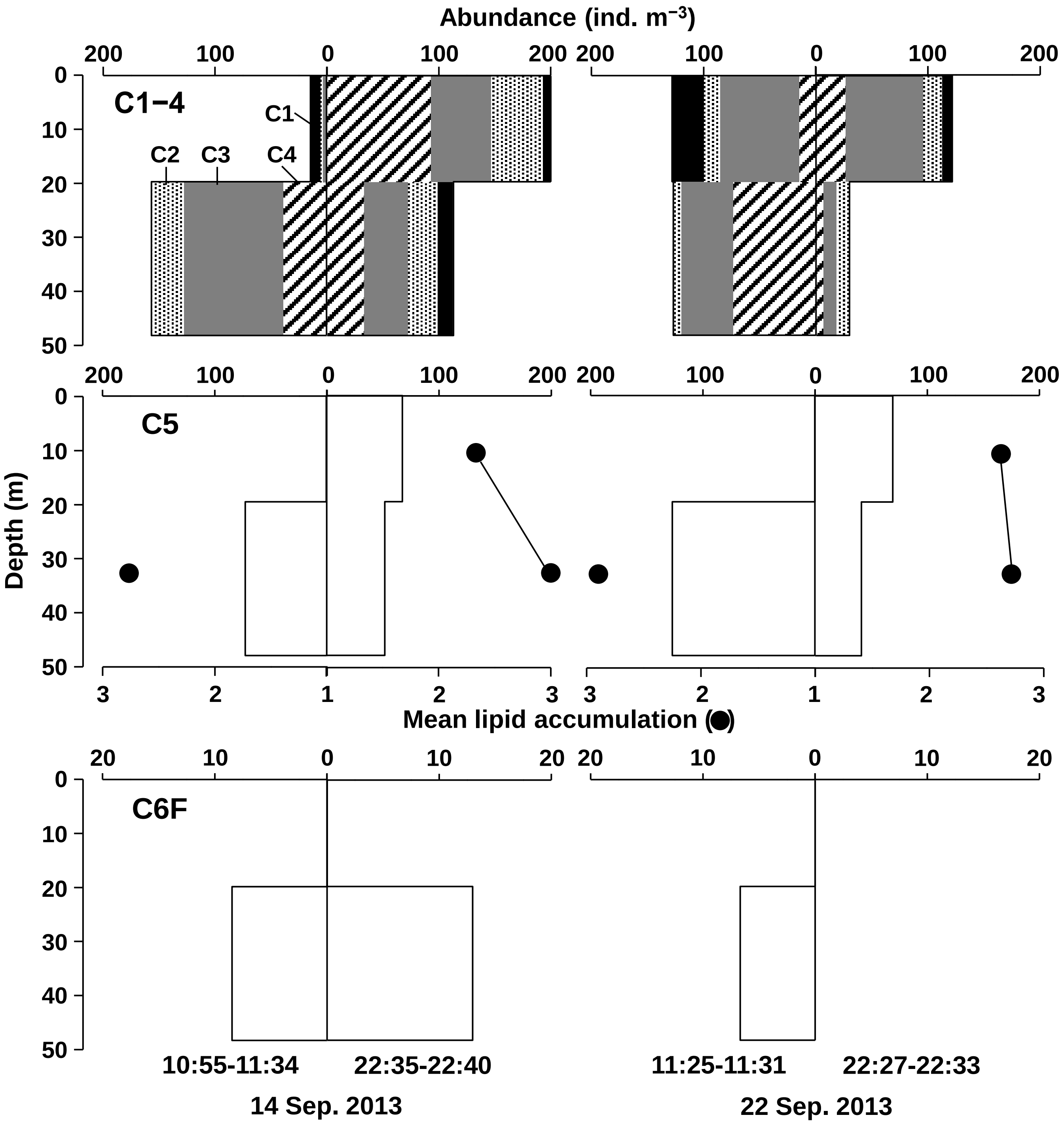


Fig. 4. (Matsuno et al.)

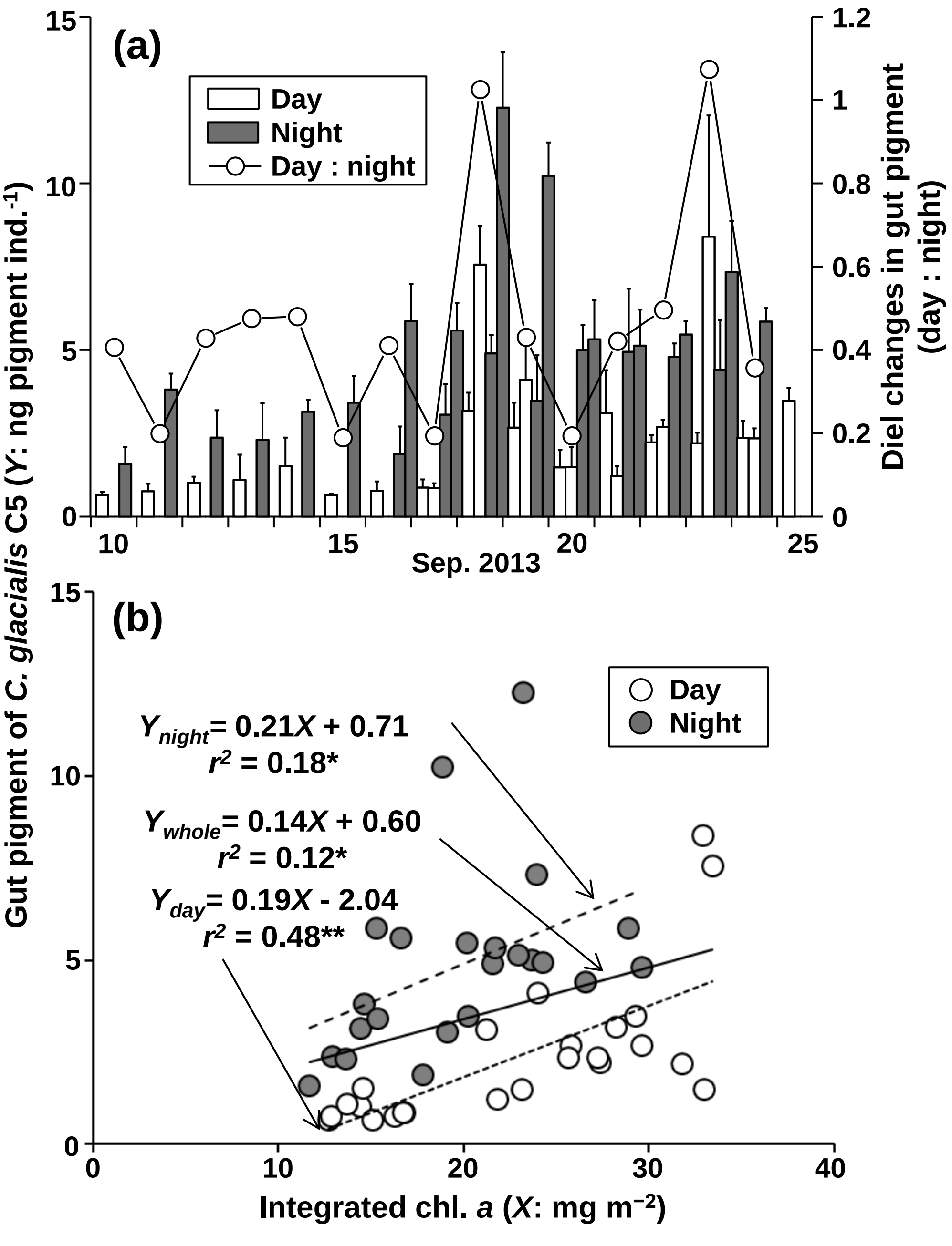


Fig. 5. (Matsuno et al.)

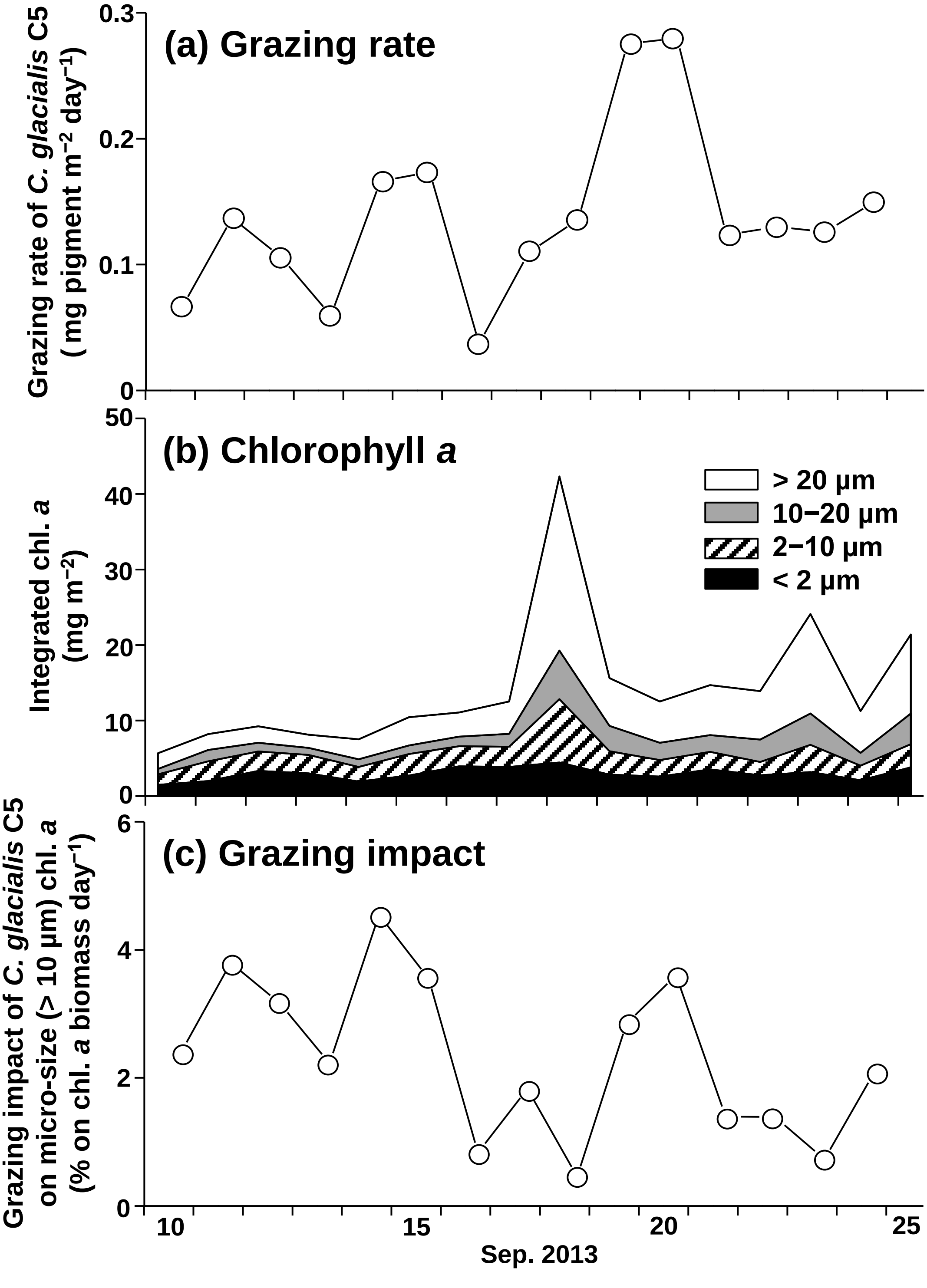


Fig. 6. (Matsuno et al.)