

1 **Short-term changes in a microplankton community in the**
2 **Chukchi Sea during autumn: Consequences of a strong**
3 **wind event**

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15 **Abstract**

16 Recent studies indicate an increase in atmospheric turbulence in the Chukchi Sea due to the
17 recent drastic sea-ice reduction during summer months. The importance of the effects of this
18 atmospheric turbulence on the marine ecosystem in this region, however, is not fully
19 understood. To evaluate the effects of atmospheric turbulence on the marine ecosystem, high-
20 frequency sampling (daily) from five layers of the microplankton community between 0 and
21 30 m at a fixed station in the Chukchi Sea from 10 through 25 September 2013 was conducted.
22 During the study period, a strong wind event (SWE) was observed on 18 and 19 September.
23 The abundance of microplankton was 2.6 to 17.6 cells ml⁻¹, with a maximum abundance
24 being reported at 20 m on 22 September, while diatoms were the most dominant taxa
25 throughout the study period. The abundance of diatoms, dinoflagellates and ciliates ranged

1 between 1.6 and 14.1 cells ml⁻¹, 0.5 and 2.4 cells ml⁻¹ and 0.1 and 2.8 cells ml⁻¹, respectively.
2 Diatoms belonging to seven genera consisting of 35 species (*Cylindrotheca closterium* and
3 *Leptocylindrus danicus* were dominant), dinoflagellates belonging to seven genera consisting
4 of 25 species (*Prorocentrum balticum* and *Gymnodinium* spp. were dominant) and ciliates
5 belonging to seven genera consisting of eight species (*Strobilidium* spp. and *Strombidium* spp.
6 were dominant) were identified. Within the microplankton species, there were 11 species
7 with abundances that increased after the SWE, while there was no species with an abundance
8 that decreased following the SWE. It is conjectured that atmospheric turbulences, such as that
9 of an SWE, may supply sufficient nutrients to the surface layer that subsequently enhance the
10 small bloom under the weak stratification of the Chukchi Sea shelf during the autumn months.
11 After the bloom, the dominant diatom community then shifts from centric-dominated to one
12 where centric/pennate are more equal in abundance.

13 **1 Introduction**

14 In the marine ecosystem of the western Arctic Ocean, microplankton, including diatoms,
15 dinoflagellates and ciliates, play several roles, such as primary producers, consumers and food
16 resources for mesozooplankton (Sherr and Sherr, 1988, Sherr et al., 1997; Olson and Strom,
17 2002). The microplankton community in the western Arctic Ocean is divided into three
18 groups - shelf, continental slope and basin (Sukhanova et al., 2009; Matsuno et al., 2014). As
19 a special characteristic, during the summer, the development of pycnocline prevents the
20 supply of nutrients to the surface layer, and phytoplankton (as determined by chlorophyll *a*)
21 form a maximum subsurface layer that may be between 20 and 30 m in depth (Hill and Cota,
22 2005; Sukhanova et al., 2009; Joo et al., 2012). With respect to the microplankton community
23 on the shelf of the Chukchi Sea, diatoms are the dominant taxa both in abundance and
24 biomass (Matsuno et al., 2014; Yang et al., in press). Regarding temporal changes in the
25 microplankton community, seasonal comparisons with 3- to 4-month sampling intervals
26 (Sukhanova et al., 2009) and year-round changes with 8-day intervals were reported (Sherr et
27 al., 2003). As microplankton grow rapidly (Strom and Fredrickson, 2008; Sherr et al., 2009),
28 fine temporal resolution (every day) is required to evaluate detailed temporal changes in their
29 community. However, such high-frequency sampling of microplankton has not been
30 conducted previously.

31 In recent years, a drastic decrease in sea ice has been reported for the western Arctic

1 Ocean during the summer months and even greater related changes in sea surface
2 temperatures have been reported (Stroeve et al., 2007; Steele et al., 2008). The changes in sea
3 surface temperatures, increases in the frequency and intensity of cyclones, and northward
4 shifts from their tracks during the summer months as well as during other seasons have also
5 been reported (Serreze et al., 2000; McCabe et al., 2001; Sepp and Jaagus, 2011). While these
6 changes are important, little is known about the effects of atmospheric and oceanic changes
7 on the marine ecosystem in the western Arctic Ocean. During the period from 10 to 25
8 September 2013, high-frequency (daily) sampling and observations were conducted at a fixed
9 station in the western Arctic Ocean, and the occurrence of strong wind events (SWEs),
10 vertical flux of nutrients and changes in primary production were reported (Nishino et al.,
11 2015). However, it is not clear how the microplankton assemblages - diatoms, dinoflagellates,
12 ciliates - respond to the SWEs and the changes in nutrient supply and primary production.

13 In the present study, we evaluate short-term changes in the microplankton community
14 in the Chukchi Sea during the autumn months by quantification of both autotrophic and
15 heterotrophic microplankton assemblages - diatoms, dinoflagellates, ciliates - based on the
16 samples collected during the same timeframe as Nishino et al. (2015). Note that we only
17 observed microplankton and did not quantify nano-and pico-plankton in this paper. We
18 conducted a cluster analysis based on microplankton abundance and evaluated the effect of
19 SWEs on microplankton assemblages under weak stratification in the Chukchi Sea due to
20 atmospheric cooling during the autumn months.

21 **2 Materials and Methods**

22 **2.1 Field sampling**

23 Water samples were collected from a fixed station in the Chukchi Sea (72°45'N, 168°15'W,
24 depth 56 m) between 10 and 25 September 2013 (Fig. 1). At approximately 9:30 am (local
25 time) every day, 12 L of seawater was collected from depths of 0, 5, 10, 20 and 30 m using a
26 rosette multi-sampler mounted on a CTD (Sea-Bird Electronics). A total of 80 samples were
27 collected (16 days × 5 depths). Temperature and salinity were measured using CTD, and 1-L
28 water samples were preserved with 1% glutaraldehyde and stored in a dark cold room.
29 Nutrients (nitrate, nitrite, ammonium and silicic acid) were measured on 10-mL water
30 samples using an autoanalyser (Bran + Luebbe GmbH, TRAACS-800). For each sample,

1 duplicate 1-L seawater samples were filtered through a GF/F filter, and chlorophyll *a* (chl *a*)
2 was measured with a fluorometer (Turner Design, Inc., 10-AU-005).

3 **2.2 Microplankton analysis**

4 In a land laboratory, 1-L preserved samples were concentrated to 18 ml with the settlement of
5 microplankton cells at the bottom of the bottle and a syphon was used to drain the clear water
6 from the top. To obtain cell counts of diatoms and ciliates, subsamples (0.1 to 0.2 ml) were
7 mounted on a glass slide and counted under an inverted microscope. For species
8 identification, we referenced Hasle and Syvertsen (1997) and Hoppenrath et al. (2009) for
9 diatoms and Maeda (1997) and Taniguchi (1997) for ciliates. To distinguish thecate and
10 athecate forms for cell counts of dinoflagellates, after staining subsamples with calcofluor (1
11 mg ml⁻¹) for more than 1 hour, subsamples (0.1 to 0.2 ml) were mounted on a glass slide and
12 counted under an epifluorescence microscope with UV light excitation (Fritz and Triemer,
13 1985). For species identification of dinoflagellates, we referenced Fukuyo et al. (1997) and
14 Hoppenrath et al. (2009). From each sample, we counted and identified cells that were larger
15 than 10 µm. Because we did not check pigments in the cell, so the nutrition of dinoflagellates
16 (heterotrophs, autotrophs and mixotrophs) was not distinguishable in this study.

17 **2.3 Statistical analysis**

18 For cluster analysis, the abundance (*X*: cells L⁻¹) of diatoms was log-transformed (Log₁₀[*X* +
19 1]) prior to the analysis to reduce any bias in abundances (Field et al., 1982). Similarities
20 between samples were examined using the Bray-Curtis method (Bray-Curtis, 1957). To
21 group the samples, similarity indices were coupled with hierarchical agglomerative clustering
22 using a complete linkage method - the unweighted pair group method - using the arithmetic
23 mean, UPGMA (Field et al., 1982). All analyses were performed using PRIMER v6
24 (PRIMER-E Ltd.). We evaluated differences in abundances of each species between groups
25 using a one-way ANOVA and post-hoc Tukey-Kramer tests. During the study period, a SWE
26 was observed on approximately 19 to 22 September (Kawaguchi et al., 2015; Nishino et al.,
27 2015). According to Kawaguchi et al. (2015), there were meteorologically and
28 oceanographically distinct periods between 10 and 18 September and 19 and 26 September,
29 represented as terms I and II, respectively. Term II was characterized by longer, stronger
30 northeasterly winds, which continued for several days between 19 and 22 September, the
31 average intensity of which was greater than 13 m s⁻¹. To evaluate the effect of the SWE, the

1 abundances of each microplankton taxon and species were compared “before the SWE (10–18
2 September)” and “after the SWE (19–25 September)” using the U test. This statistical
3 analysis was performed using StatView.

4 **3 Results**

5 **3.1 Hydrography**

6 Through the sampling period, temperatures ranged from -1.5 to 3.3°C (Fig. 2a). Cold water
7 below 0°C was observed at depths below 20 m, and thermocline occurred at approximately 25
8 m. The temperatures in the upper thermocline decreased from 3 to 1.5°C during the study
9 period. Salinity ranged from 31.0 to 32.7, and high-salinity water (> 32) was observed at
10 depths below 20 m. Halocline was observed at approximately 25 m, which paralleled that of
11 the thermocline. Salinity in the upper halocline increased from 31.1 at the start of the
12 sampling period (10 September) to 31.6 at the end of the sampling period (25 September) (Fig.
13 2b). From Sigma-T, the development of pycnocline was observed at approximately 20 to 30
14 m during the study period (Fig. 2c). DIN (dissolved inorganic nitrogen: $\text{NO}_3^- + \text{NO}_2^- + \text{NH}_4^+$)
15 concentration ranged from 0.02 to 18.1 μM , while the nutricline was observed at
16 approximately 30 to 40 m (Fig. 2d). Silicates ranged from 0.5 to 32.3 μM , and their nutricline
17 was observed at approximately 40 to 50 m. Compared with DIN, silicate concentration was
18 relatively higher (> 2 μM even at the surface layer) (Fig. 2e). Chl *a* ranged from 0.1 to 3.2 μg
19 L^{-1} , and relatively high chl *a* was observed at depths less than 30 m (Fig. 2f). After the SWE,
20 chl *a* increased in the upper 30 m and remained high until the end of the study period. It is
21 notable that the sporadic high chl *a* was observed at approximately 25 m on 18, 19 and 22
22 September – the days following the SWE.

23 **3.2 Microplankton assemblage**

24 In the present study, diatoms belonging to 7 genera and 35 species, dinoflagellates belonging
25 to 7 genera and 25 species, and ciliates belonging to 7 genera and 8 species were identified
26 (Table 1). Within the microplankton species, 11 species increased in abundance after the
27 SWE, while no species decreased in abundance after the SWE (Table 1).

1 **3.3 Diatoms**

2 The mean abundance of diatoms (0 to 30 m) ranged from 1.6 to 14.1 cells ml⁻¹. The dominant
3 species for centric diatoms was *Leptocylinthus danicus*, while the dominant species for
4 pennate diatoms was *Cylindrotheca closterium* (Fig. 3a). Centric diatoms showed a
5 maximum abundance on 16 September (before the SWE) (Fig. 3b), while pennate diatoms
6 increased in abundance throughout the water column after 20 September (after the SWE) (Fig.
7 3c). With respect to the diatoms, 5 species increased in abundance after the SWE -
8 *Chaetoceros furcellatus* (resting spore), *Dactyliosolen fragilissimus* and *Rhizosolenia* spp. for
9 centric diatoms, and *Cylindrotheca closterium* and *Navicula* spp. for pennate diatoms (Table
10 1).

11 **3.4 Dinoflagellates**

12 The mean abundance of dinoflagellates (0 to 30 m) ranged from 0.5 to 2.4 cells ml⁻¹. The
13 dominant species of thecate dinoflagellates was *Prorocentrum balticum* and *Gymnodinium*
14 spp. for athecate dinoflagellates (Fig. 4a). Temporal changes in vertical distribution were
15 similar for thecate and athecate dinoflagellates, with both exhibiting high abundance at 20 m
16 on 15 September and at 5 m on 19 September (Fig. 4b, c). Five thecate dinoflagellate species
17 increased in abundance after the SWE - *Alexandrium tamarense*, *Oxytoxum* sp. 2,
18 *Protoperidinium bipes*, *P. conicum*, and *P. pellucidum* (Table 1).

19 **3.5 Ciliates**

20 Mean abundance of ciliates (0 to 30 m) ranged from 0.1 to 2.8 cells ml⁻¹. The dominant
21 species were the oligotrich ciliates *Strobilidium* spp. and *Strombidium* spp. (Fig. 5a).
22 Temporal changes in vertical distribution varied between oligotrich and tintinnid ciliates. For
23 oligotrich ciliates, high abundances were observed at four-day intervals until 20 September
24 (Fig. 5b). For tintinnid ciliates, high abundance was noted after 22 September (Fig. 5c). Only
25 one ciliate species (tintinnid *Ptychocylis obtusa*) increased in abundance after the SWE (Table
26 1).

27 **3.6 Temporal and spatial changes in community structure**

28 As a feature of microplankton assemblages in this study, diatoms were the dominant taxa
29 (comprising 68.0% of mean abundance). For dinoflagellates, the proportion of the

1 autotrophic species (such as *P. balticum* and *A. tamarense*) was low, while that of the
2 heterotrophic species (such as *Protoperidinium* spp. and *Gymnodinium* spp.) was high (Table
3 1). With this in mind, we conducted a cluster analysis based on the abundance of diatoms.
4 For other taxa (dinoflagellates and ciliates), their communities were evaluated based on the
5 relationship with communities of diatoms.

6 A cluster analysis based on diatom abundance classified their community into 5
7 groups (A to E) at 46.1, 65.9 and 78.7% dissimilarity levels (Fig. 6a). Each group contained
8 between 7 and 24 samples. The highest abundance was observed for group C, followed by
9 groups B, E, A and D. Group A exhibited no distinct dominant species, while groups B and C
10 were dominated by *L. danicus* and *C. closterium*, and group E was dominated by *C.*
11 *closterium* (Fig. 6b).

12 Comparisons between and among groups indicated that there were 8 species with
13 significantly different numbers from one group to another according to a one-way ANOVA, p
14 < 0.05 , as presented in Table 2. Compared to the other groups, group A had a higher
15 abundance of the centric diatom *Chaetoceros* sp.; group B had a higher abundance of the
16 thecate dinoflagellate *Protoceratium reticulatum*; group C had a higher abundance of the
17 centric diatom *L. danicus*, *L. minimus* and *P. alata*, the pennate diatom *C. closterium*, and the
18 thecate dinoflagellate *P. bipes*; and group E had a higher abundance of the tintinnid ciliate *P.*
19 *obtusa* (Table 2). No species were found to dominate group D.

20 With respect to temporal and vertical distribution of each group, group D dominated
21 the water column on 10 September (Fig. 6c). From 12 to 18 September, group B dominated
22 at the 0 to 20 m level in the water column, while other groups were observed to dominate on
23 various occasions. For example, from 19 to 23 September, after the SWE, group C dominated
24 the water column group. After that, group E was found to be dominant on 24 and 25
25 September. At the greatest depth, 30 m, group A was dominant throughout most of the study
26 period.

27 **4 Discussion**

28 **4.1 Characteristics of a microplankton community**

29 To obtain information on the microplankton community in the Chukchi Sea, geographical

1 changes in community structure during the summer months (Joo et al., 2012; Matsuno et al.,
2 2014; Yang et al., in press) as well as seasonal and horizontal changes in diatoms (Sukhanova
3 et al., 2009) were recorded. Because the study region and season were comparable to those in
4 Matsuno et al. (2014), we compared the characteristics of the microplankton community in
5 this study. Matsuno et al. (2014) classified the microplankton community into 5 groups (A to
6 E) based on abundance and concluded that the grouping was strongly correlated with the
7 environmental parameters, which varied by water mass. When comparing the findings of this
8 study with the environmental parameters of Matsuno et al. (2014), ranges of surface salinity
9 (31.0–32.7) and chl *a* ($> 1 \mu\text{g L}^{-1}$) indicated that the microplankton community studied herein
10 corresponds with group B of Matsuno et al. (2014). Matsuno et al.'s (2014) group had
11 characteristics of high abundance (mean 31.0 cells ml^{-1}), a predominance of diatoms (78% of
12 mean total microplankton abundance), and the microplankton are found throughout the
13 Chukchi Sea shelf (Matsuno et al., 2014). In comparison with the Matsuno et al. (2014)
14 results, our study found a slightly lower abundance (range 2.6 to 17.6 cells ml^{-1}) and lower
15 diatom composition (65%). The variations between the two studies may be related to the
16 current study's late sampling period (10 to 25 September).

17 In the biomass base, Yang et al. (in press) divided the microplankton community in
18 this region into 3 groups – the diatom-dominated eutrophic Chukchi Sea Shelf, the
19 picoplankton-dominated oligotrophic Northwind Abyssal Plain and the picoplankton- and
20 diatom-dominated Northwind Ridge. Comparing the classifications, the diatom-dominated
21 microplankton community of this study may correspond with Yang et al.'s Chukchi Sea shelf
22 group. The dominant species of this study – the pennate diatom *C. closterium*, the thecate
23 dinoflagellate *P. balticum*, the athecate dinoflagellate *Gymnodinium* spp., and the oligotrich
24 *Strombidium* spp. – are all species that have been listed as important and that are characterised
25 in Matsuno et al.'s (2014) groups.

26 With respect to seasonal changes, diatoms ($> 5 \mu\text{m}$) and haptophytes dominated during
27 the spring months, while small prasinophytes, larger haptophytes and diatoms dominated
28 beneath the nitrate-depleted surface layer during the summer months (Hill et al., 2005). As
29 important species during the summer, *Chaetoceros* spp., *Thalassiosira* spp., *Fragilaria* sp.
30 and *Fragilariopsis* sp. were reported to dominate at the chl *a* maximum layer (Booth and
31 Horner, 1997; Coupel et al., 2012). In the autumn months, prasinophytes, which adapt to low
32 temperatures, short daylight hours and an oligotrophic environment, were found to dominate
33 (Lovejoy et al., 2007). At the ice-free surface layer without light limitations, due to the

1 nutrient depletion at the surface layer, phytoplankton, mainly diatoms, are known to exist in
2 the subsurface layer at a maximum depth of 20–30 m (Cota et al., 1996; Hill and Cota, 2005;
3 Sukhanova et al., 2009; Joo et al., 2012). In the present study, nutrient (DIN and silicate)
4 depletion and the occurrence of the sporadic subsurface chl *a* maximum corresponded well
5 with the aforementioned studies (Fig. 2d, f). During winter months, diatoms (> 20 µm) and
6 pigmented dinoflagellates were less than 1 cell ml⁻¹ and ciliates (mostly oligotrich) ranged
7 from 0.1 to 2 cells ml⁻¹ (Sherr et al., 2003).

8 Compared with these seasonal patterns, the subsurface chl *a* maximum in the present
9 study corresponded with the characteristics from summer to autumn, while the low abundance
10 and dominant species of dinoflagellates and ciliates are similar to the characteristics exhibited
11 during the winter. Given the occurrence of resting spores of diatoms, as referenced in this
12 study (Table 1), the seasonal succession of the microplankton species and community from
13 summer to winter began during the study period.

14 **4.2 Short-term changes in the microplankton community**

15 The hydrographic condition of the Arctic Ocean means that low salinity occurs at surface
16 layer due to the melting of sea ice during the summer months, while high salinity is the result
17 of brine, which occurs during the formation of sea ice during winter months (Macdonald et al.,
18 2002; Nishino et al., 2011). Throughout the study period, sea surface temperatures decreased
19 while salinity gradually increased (Fig. 2). These environmental changes may result from the
20 following processes - atmospheric cooling during autumn induces high density sea surface
21 water and weakens the density of the pycnocline layer, which then promotes the mixing of the
22 cold and the saline deep water. From 10 to 14 September, less saline ice-melt water was
23 found in the surface layer, the pycnocline layer formed at approximately 25 m, and nutrient-
24 rich and saline Pacific summer water was found beneath the ice-melt water (Fig. 2c) (Nishino
25 et al., 2015). It was noted that the SWE, which was observed from 18 to 19 September,
26 temporally weakened the pycnocline layer, thus causing vertical mixing to occur, which then
27 resulted in the supply of rich nutrients to the surface layer (Nishino et al., 2015).

28 A schematic diagram of short-term changes in the microplankton community and the
29 dominant species during the study (10 to 25 September) is presented in Fig. 7. Based on the
30 dominant species and community structure during the study period, the microplankton
31 community was classified into 5 phases, each of which occurred at 2- to 5-day intervals. Thus,

1 from 10 to 14 September, the abundance of most species as well as the levels of chl *a* were
2 low, possibly due to the warm, low saline ice-melt water (phase 1). On 15 and 16 September,
3 the abundance of the centric diatoms *C. convolutus* and *L. danicus* increased (phase 2). This
4 sudden increase in diatom abundance in phase 2, which exceeded the range reported for
5 diatom growth (0.35–0.4 d⁻¹) in this region (Strom and Fredrickson, 2008; Sherr et al., 2009),
6 could not be explained by cell division growth within the same water masses. Accordingly, as
7 an alternative cause, Nishino et al. (2015) reported that the displacement of the ice-melt
8 seawater during this period caused the horizontal movement of water masses, which, in turn,
9 may have led to the sudden increase in diatoms during this phase.

10 On 17 and 18 September, diatom abundance decreased while there was an increase in
11 the thecate dinoflagellate *A. tamarense*, *P. balticum*, *Protoperidinium* spp., the athecate
12 dinoflagellate *Gymnodinium* spp., and the oligotrich ciliates *Strobilidium* spp. and
13 *Strombidium* spp. (Fig. 7). Within these species, the heterotrophic *Gymnodinium* spp. and
14 *Protoperidinium* spp. are known to prey on diatoms and, thus, strongly regulate the
15 phytoplankton community (Olson and Strom, 2002). Therefore, these increases in
16 microzooplankton and the decrease in diatoms may be caused by microzooplankton grazing
17 on diatoms.

18 In phase 3, 18 and 19 September, the SWE occurred (Nishino et al., 2015). Effects of
19 the SWE included a decrease in temperature and an increase in salinity and chl *a* (Fig. 7).
20 The dominant microplankton group also changed to group C, which was characterized by the
21 high abundance of the majority of the species (Fig. 6b). Interestingly, chl *a* almost doubled
22 from phase 2 to 3, while the abundance of diatoms (primary autotrophic taxa) increased only
23 slightly during this phase. According to Onodera and Nishino (2014), the discrepancy
24 between chl *a* and diatom abundance may be caused by the time-lag in the physiological
25 response of diatoms to the supply of nutrients. That is, diatoms may first use added nutrients
26 from the increase in chl *a* pigment within the cell and then perform cell division, which is
27 delayed due to the increase in chl *a*, within 3 to 4 days (Fig. 7). An additional characteristic
28 of phase 3 was the remarkable and substantial increase in the abundance of oligotrich ciliates
29 *Strobilidium* spp. and *Strombidium* spp. It is well known that the growth rate of heterotrophic
30 microprotists varies with taxa. For example, the oligotrich ciliates grow faster than do the
31 dinoflagellates (Hansen and Jensen, 2000). Thus, the oligotrich ciliates may respond more
32 quickly than the dinoflagellates to an increase in autotrophs, an event that enhances the supply
33 of nutrients caused by the SWE.

1 From 22 to 23 September, most of the microplankton species increased in abundance
2 and formed a small bloom (phase 4). As a characteristic of this small bloom, the abundance
3 of the pennate diatom *C. closterium* increased dramatically. While pennate diatoms were very
4 low in abundance before the SWE, they increased significantly after the SWE (Fig. 3c, Table
5 1). This increase in pennate diatoms may imply that they respond to the supply of nutrients
6 from the deeper layer through the pycnocline layer after the SWE (Alcoverro et al., 2000).

7 From 24 to 25 September, the dominant microplankton group shifted to group E,
8 which is characterised by a high abundance of *C. closterium*, a diatom frequently observed in
9 sea ice (Booth and Horner, 1997). Because of the nutrient depletion after the bloom, centric
10 diatoms such as *L. danicus* may have formed resting spores (Davis et al., 1980) and sank, thus
11 causing the shift in dominant taxa from centric diatoms to pennate diatoms by the end of this
12 study (phase 5). The microplankton community in the upper layer (0 to 20 m) demonstrated
13 clear temporal changes within a 2- to 5-day interval. In contrast to the shallower layer, the
14 microplankton community at the deepest sampling depth (30 m) was composed of groups A
15 and D, both of which were characterised by low abundance throughout the study period (Fig.
16 6c). Because the pycnocline layer was observed at approximately 25 m (Fig. 2a, b, c), these
17 two groups may form in that layer.

18 Throughout this study, it was revealed that atmospheric turbulence, such as SWE, may
19 supply sufficient nutrients to the surface layer, which subsequently enhances a small bloom
20 under the weak stratification of the Chukchi Sea Shelf during the autumn months. After the
21 bloom, the dominant diatom community shifts from centric diatoms to pennate diatoms, thus
22 suggesting that a SWE accelerates the seasonal succession of the microplankton community
23 from summer to winter. Such a SWE-enhanced small bloom in autumn may be fed upon by
24 copepods (*Calanus glacialis*) immediately (Matsuno et al., 2015). Thus, Matsuno et al.
25 (2015) suggested that the temporal phytoplankton bloom caused by the atmospheric
26 turbulence (SWE) during autumn may have had a positive indirect effect on the
27 mesozooplankton (SWE → nutrient supply from the deep layer → small phytoplankton
28 bloom → copepod feeding) within a short period.

29 **Authors' contributions**

30 S.N., J.I. and T.K. designed and coordinated this research project. S.N. and J.I. were chief
31 scientists during the MR13-06 cruise of R.V. *Mirai*. K.M. collected the water samples during
32 the cruise. N.Y. conducted species identification and the enumeration of the microplankton

1 samples in the land laboratory. M.I. and J.O. gave variable comments to analyse the
2 microplankton community. N.Y. and A.Y. wrote the manuscript with contributions from all
3 co-authors.

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28

1 **Figure captions**

2 **Figure 1.** Location of the sampling station in the Chukchi Sea. Depth contours at 50, 100
3 and 1000 m are superimposed.

4 **Figure 2.** Temporal and vertical changes in temperature (°C) (a), salinity (b), sigma-T (c),
5 dissolved inorganic nitrogen (μM) (d), silicate (μM) (e) and chlorophyll *a* ($\mu\text{g L}^{-1}$) (f)
6 at a fixed station in the Chukchi Sea between 10 and 25 September 2013. Solid bars
7 indicate the timing of the strong wind event.

8 **Figure 3.** Temporal changes in cell density and species composition of total diatoms (a), the
9 vertical distribution of centric diatoms (cells ml^{-1}) (b) and pennate diatoms (cells ml^{-1})
10 (cells ml^{-1}) (c) in the Chukchi Sea during the period 10 to 25 September 2013. In (a), values
11 represent the mean of diatom abundance between 0 and 30 m. Solid bars indicate the
12 timing of a strong wind event.

13 **Figure 4.** Temporal changes in cell density and species composition of total dinoflagellates
14 (a), vertical distribution of thecate dinoflagellates (cells ml^{-1}) (b) and athecate
15 dinoflagellates (cells ml^{-1}) (c) in the Chukchi Sea for the period 10 to 25 September
16 2013. In (a), values represent the mean of dinoflagellate abundance between 0 and
17 30 m. Solid bars indicate the timing of a strong wind event.

18 **Figure 5.** Temporal changes in cell density and species composition of total ciliates (a), the
19 vertical distribution of oligotrich ciliates (cells ml^{-1}) (b) and tintinnid ciliates (cells
20 ml^{-1}) (c) in the Chukchi Sea during the period from 10 to 25 September 2013. In (a),
21 values represent the mean ciliate abundance between 0 and 30 m. Solid bars indicate
22 the timing of a strong wind event.

23 **Figure 6.** (a) Results of cluster analysis based on diatom cell density in the Chukchi Sea from
24 10 to 25 September 2013. Five groups (A to E) were identified at 46 to 78% Bray-
25 Curtis dissimilarity connected using UPGMA. Numbers in parentheses indicate the
26 number of samples in each group. (b) Mean abundance and species composition of
27 each group. (c) Vertical and temporal distribution of each group. Solid bar in (C)
28 indicates the timing of a strong wind event.

29 **Figure 7.** Schematic diagram of temporal changes in environmental parameters (upper panel),
30 diatom community (middle bar) and abundance of dominant microplanktonic species
31 (lower panel) at a water column of a single station in the Chukchi Sea from 10 to 25

1 September 2013. Values of the upper panel indicate integrated mean data. The solid
2 bar indicates the timing of a strong wind event. Black, grey and white in the lower
3 panel indicate relative abundance - high, middle and low, respectively - of each
4 species in a 0- to 30-m column of water. Based on a dominant community and
5 species, temporal changes in a microprotist community were divided into five phases,
6 which are indicated by the circled numbers (1 to 5) and dashed lines in the upper
7 panel. For details, see text.
8

1 **Table 1.** List of microplankton species and their mean cell densities (cells L⁻¹) at a single
2 station in the Chukchi Sea between 10 and 18 September (before SWE) and 19 and
3 25 September (after SWE) 2013. NS: not significant; *: $p < 0.05$; **: $p < 0.01$; ***:
4 $p < 0.001$.

Species	Before SWE (10–18 Sep.)	After SWE (19–25 Sep.)	<i>U</i> -test
Centric diatoms			
<i>Chaetoceros affinis</i>	308	113	NS
<i>Chaetoceros borealis</i>	28	67	NS
<i>Chaetoceros compressus</i>	224	273	NS
<i>Chaetoceros convolutus</i>	120	237	NS
<i>Chaetoceros concavicornis</i>	424	730	NS
<i>Chaetoceros decipience</i>	52	77	NS
<i>Chaetoceros furcellatus</i> (resting spore)	12	252	**
<i>Chaetoceros laciniosus</i>	28	113	NS
<i>Chaetoceros</i> sp.	48	108	NS
<i>Dactyliosolen fragilissimus</i>	0	139	*
<i>Leptocylindrus danicus</i>	2068	2186	NS
<i>Leptocylindrus danicus</i> (resting spore)	84	5	NS
<i>Leptocylindrus minimus</i>	424	129	NS
<i>Proboscia alata</i>	316	617	NS
<i>Rhizosolenia borealis</i>	20	15	NS
<i>Rhizosolenia setigera</i>	172	118	NS
<i>Rhizosolenia</i> spp.	0	21	*
Pennate diatoms			
<i>Cylindrotheca closterium</i>	700	3111	***
<i>Navicula</i> spp.	0	15	*
Thecate dinoflagellates			
<i>Alexandrium tamarense</i>	68	157	*
<i>Ceratium horridum</i>	0	3	NS
<i>Gonyaulax scrippsae</i>	2	8	NS
<i>Gonyaulax</i> spp.	6	3	NS
<i>Oxytoxum</i> sp.1	98	72	NS
<i>Oxytoxum</i> sp.2	2	15	*
<i>Prorocentrum balticum</i>	192	203	NS
<i>Prorocentrum compressum</i>	0	5	NS
<i>Prorocentrum minimum</i>	16	36	NS
<i>Protoceratium reticulatum</i>	40	26	NS
<i>Protoperidinium avellanum</i>	68	95	NS
<i>Protoperidinium bipes</i>	56	177	**
<i>Protoperidinium conicum</i>	0	10	**
<i>Protoperidinium leonis</i>	0	3	NS
<i>Protoperidinium marukawai</i>	12	10	NS

<i>Protooperidinium mite</i>	0	3	NS
<i>Protooperidinium monovelum</i>	34	28	NS
<i>Protooperidinium pellucidum</i>	0	21	**
<i>Protooperidinium punctulatum</i>	96	90	NS
<i>Protooperidinium subinerme</i>	4	3	NS
<i>Protooperidinium thorianum</i>	76	80	NS
<i>Protooperidinium</i> sp.1	4	0	NS
<i>Protooperidinium</i> spp.	2	3	NS
<i>Scripsiella crystallina</i>	28	64	NS
Athecate dinoflagellates			
<i>Gymnodinium</i> spp.	628	573	NS
Oligotrich ciliates			
<i>Lohmanniella</i> spp.	16	21	NS
<i>Strobilidium</i> spp.	408	638	NS
<i>Strombidium strobilum</i>	56	26	NS
<i>Strombidium</i> spp.	720	962	NS
<i>Tontonia gracillima</i>	72	67	NS
Tintinnid ciliates			
<i>Parafavella denticulata</i>	4	0	NS
<i>Ptychocylis obtusa</i>	12	57	*
<i>Tintinnopsis</i> sp.	8	0	NS

1

2

1 **Table 2.** Mean cell densities (cells L⁻¹) of microplankton in each group identified by cluster
2 analysis (cf. Fig. 6) in the Chukchi Sea between 10 and 25 September 2013.
3 Numbers in parentheses indicate number of samples included. Differences between
4 groups were tested by one-way ANOVA and Tukey-Kramer tests. Any groups not
5 connected by underlines are significantly different ($p < 0.05$). NS: not significant; *:
6 $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Species	Group					one-way ANOVA	Tukey-Kramer test				
	A (14)	B (22)	C (24)	D (7)	E (13)						
Centric diatoms											
<i>Chaetoceros affinis</i>	475.7	458.2	45.0	0	0	NS					
<i>Chaetoceros borealis</i>	77.1	32.7	22.5	0	96.9	NS					
<i>Chaetoceros compressus</i>	77.1	343.6	457.5	0	0	NS					
<i>Chaetoceros concavicornis</i>	154.3	286.4	90.0	51.4	207.7	NS					
<i>Chaetoceros convolutus</i>	257.1	523.6	817.5	514.3	484.6	NS					
<i>Chaetoceros decipience</i>	38.6	81.8	112.5	0	0	NS					
<i>Chaetoceros furcellatus</i> (resting spore)	205.7	32.7	142.5	77.1	138.5	NS					
<i>Chaetoceros laciniosus</i>	25.7	90.0	120.0	0	0	NS					
<i>Chaetoceros</i> sp.	257.1	8.2	60.0	102.9	0	*		<u>B</u>	<u>C</u>	<u>D</u>	<u>A</u>
<i>Dactyliosolen fragilissimus</i>	192.9	98.2	0	0	0	NS					
<i>Leptocylindrus danicus</i>	90.0	2593.6	4590.0	25.7	69.2	***	<u>D</u>	<u>E</u>	<u>A</u>	<u>B</u>	<u>C</u>
<i>Leptocylindrus danicus</i> (resting spore)	192.9	0	52.5	0	0	NS					
<i>Leptocylindrus minimus</i>	90.0	310.9	585.0	77.1	0	**	<u>E</u>	<u>D</u>	<u>A</u>	<u>B</u>	<u>C</u>
<i>Proboscia alata</i>	64.3	310.9	1050.0	51.4	193.8	***	<u>D</u>	<u>A</u>	<u>E</u>	<u>B</u>	<u>C</u>
<i>Rhizosolenia borealis</i>	12.9	8.2	30.0	25.7	13.8	NS					
<i>Rhizosolenia setigera</i>	205.7	90.0	180.0	102.9	152.3	NS					
<i>Rhizosolenia</i> spp.	12.9	8.2	7.5	0	13.8	NS					
Pennate diatoms											
<i>Cylindrotheca closterium</i>	205.7	1178.2	3060.0	411.4	2713.8	***	<u>A</u>	<u>D</u>	<u>B</u>	<u>E</u>	<u>C</u>
<i>Navicula</i> spp.	0	16.4	7.5	0	0	NS					
Thecate dinoflagellates											
<i>Alexandrium tamarense</i>	38.6	110.5	131.3	25.7	173.1	NS					
<i>Ceratium horridum</i>	0	0	0	0	6.9	NS					
<i>Gonyaulax scrippsae</i>	6.4	4.1	3.8	0	6.9	NS					
<i>Gonyaulax</i> spp.	0	12.3	0	0	6.9	NS					
<i>Oxytoxum</i> sp. 1	96.4	90.0	82.5	51.4	96.9	NS					
<i>Oxytoxum</i> sp. 2	0	4.1	7.5	0	27.7	NS					

<i>Prorocentrum balticum</i>	102.9	237.3	191.3	167.1	256.2	NS				
<i>Prorocentrum compressum</i>	6.4	0	3.8	0	0	NS				
<i>Prorocentrum minimum</i>	19.3	20.5	41.3	12.9	13.8	NS				
<i>Protoceratium reticulatum</i>	0	69.5	30.0	12.9	27.7	*		D	E	C B
<i>Protoperidinium avellanum</i>	45.0	98.2	105.0	12.9	76.2	NS				
<i>Protoperidinium bipes</i>	12.9	130.9	168.8	0	124.6	**	A	E	B C	
<i>Protoperidinium conicum</i>	0	0	11.3	0	6.9	NS				
<i>Protoperidinium leonis</i>	0	0	3.8	0	0	NS				
<i>Protoperidinium marukawai</i>	0	24.5	7.5	0	13.8	NS				
<i>Protoperidinium mite</i>	0	0	3.8	0	0	NS				
<i>Protoperidinium monovelum</i>	19.3	61.4	33.8	0	6.9	NS				
<i>Protoperidinium pellucidum</i>	0.0	16.4	11.3	0	6.9	NS				
<i>Protoperidinium punctulatum</i>	25.7	143.2	97.5	0	124.6	NS				
<i>Protoperidinium subinerme</i>	0	8.2	0	12.9	0	NS				
<i>Protoperidinium thorianum</i>	12.9	106.4	82.5	51.4	103.8	NS				
<i>Protoperidinium</i> sp. 1	0	4.1	3.8	0	0	NS				
<i>Protoperidinium</i> spp.	0	4.1	0	0	6.9	NS				
<i>Scipsiella crystallina</i>	6.4	57.3	60.0	0	55.4	NS				
Athebate dinoflagellates										
<i>Gymnodinium</i> spp.	353.6	695.5	817.5	192.9	546.9	NS				
Oligotrich ciliates										
<i>Lohmanniella</i> spp.	12.9	8.2	30.0	25.7	13.8	NS				
<i>Strobilidium</i> spp.	360.0	515.5	757.5	308.6	304.6	NS				
<i>Strombidium strobilum</i>	0	0	105.0	51.4	41.5	NS				
<i>Strombidium</i> spp.	720.0	736.4	1087.5	180.0	955.4	NS				
<i>Tontonia gracillima</i>	64.3	49.1	135.0	0	27.7	NS				
Tintinnid ciliates										
<i>Parafavella denticulata</i>	0	0	7.5	0	0	NS				
<i>Ptychocylis obtusa</i>	12.9	16.4	30.0	0	96.9	*	A	B	C E	
<i>Tintinnopsis</i> sp.	12.9	0	7.5	0	0.0	NS				

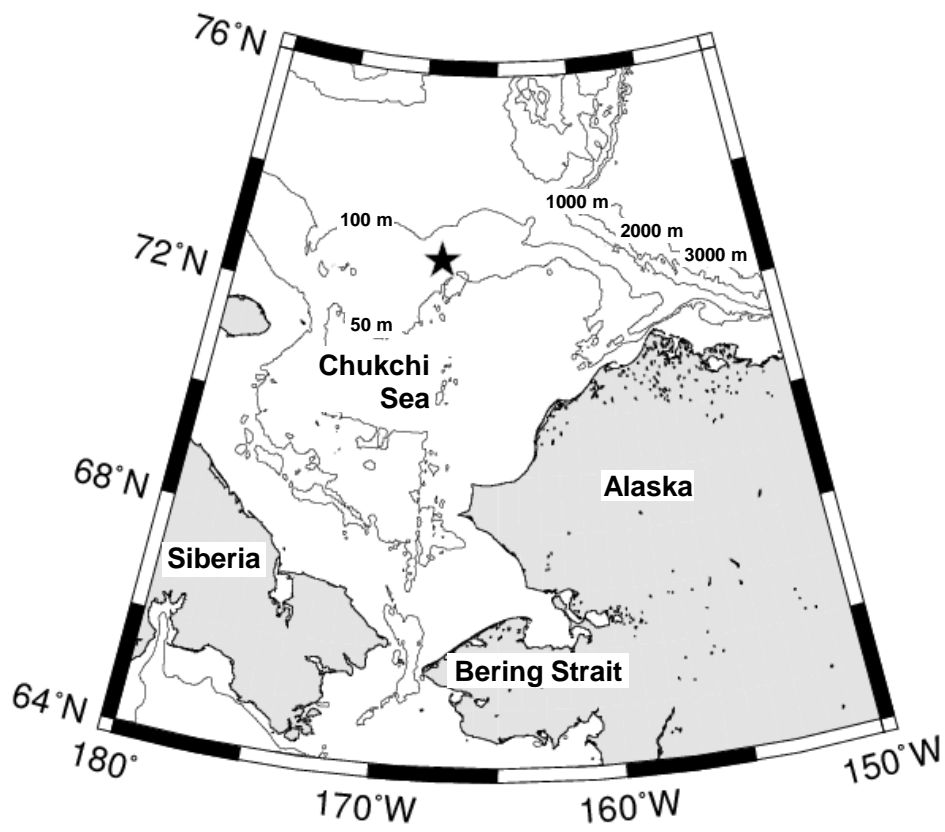


Fig. 1. (Yokoi et al.)

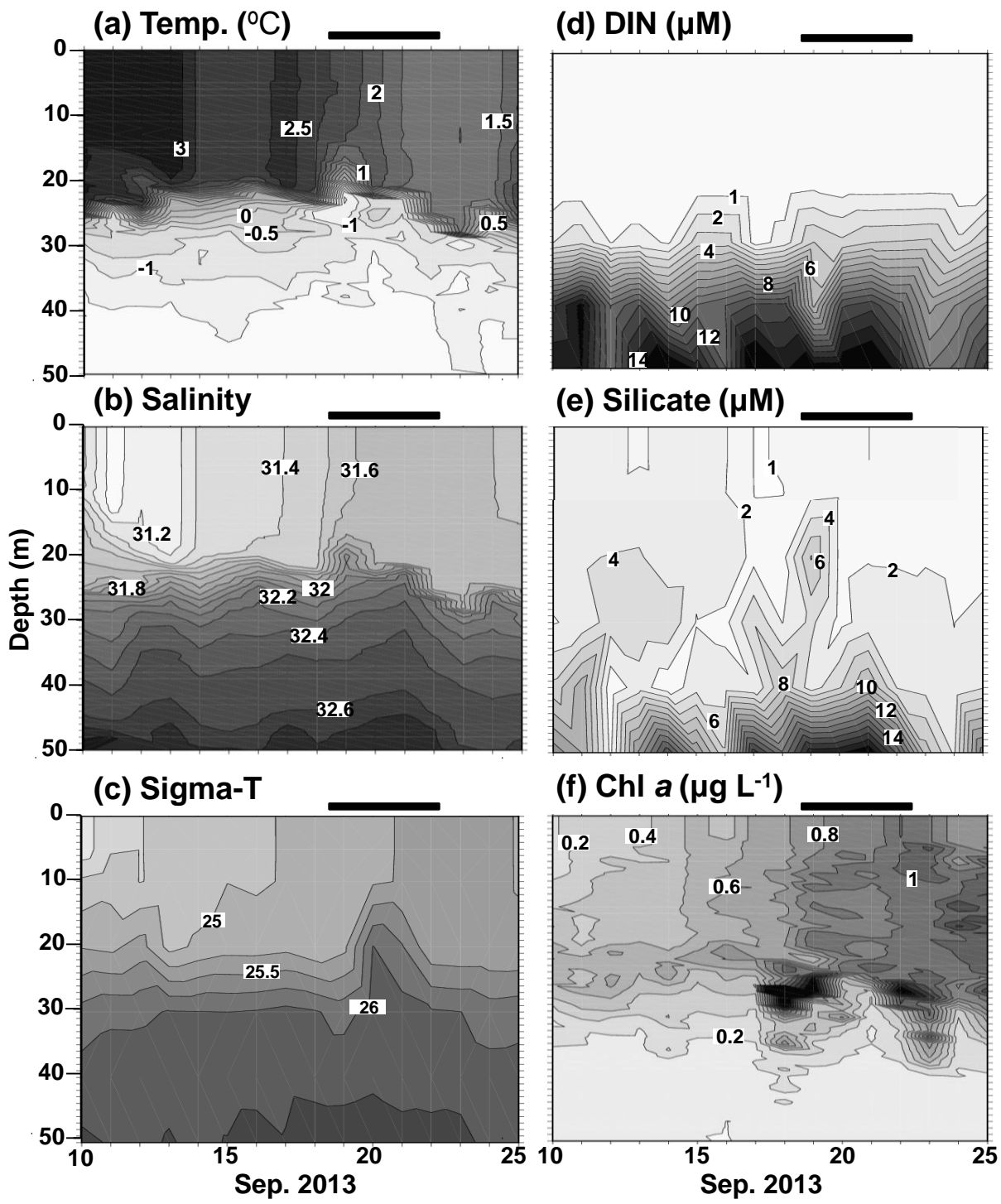


Fig. 2. (Yokoi et al.)

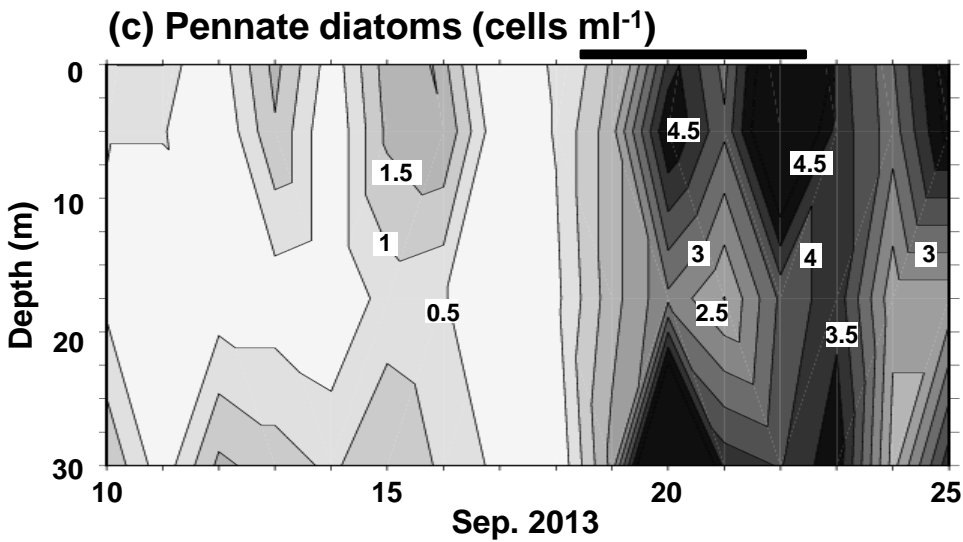
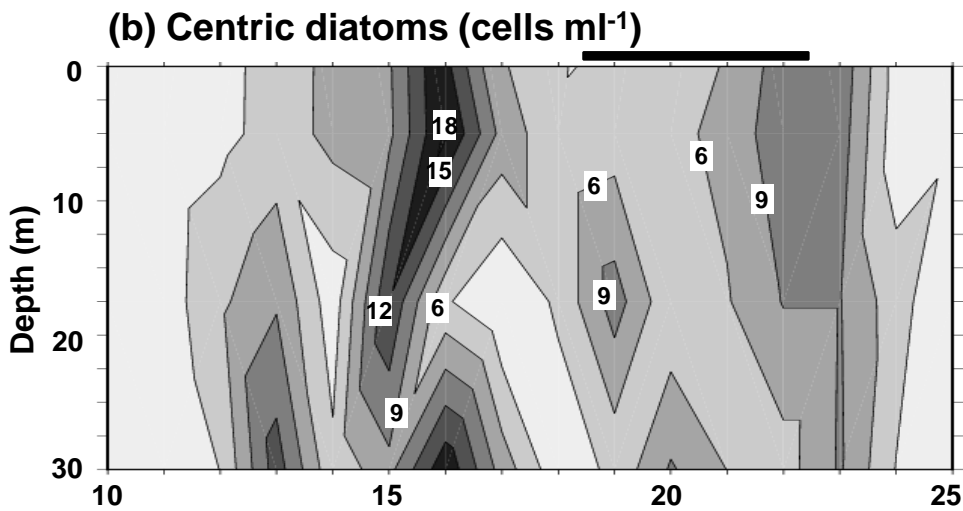
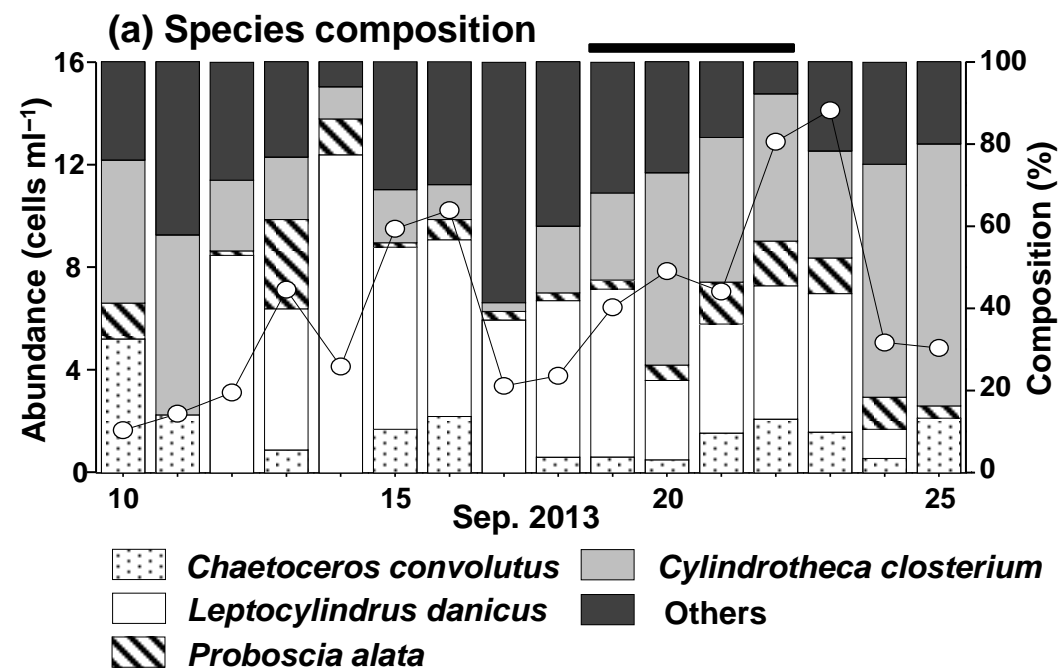


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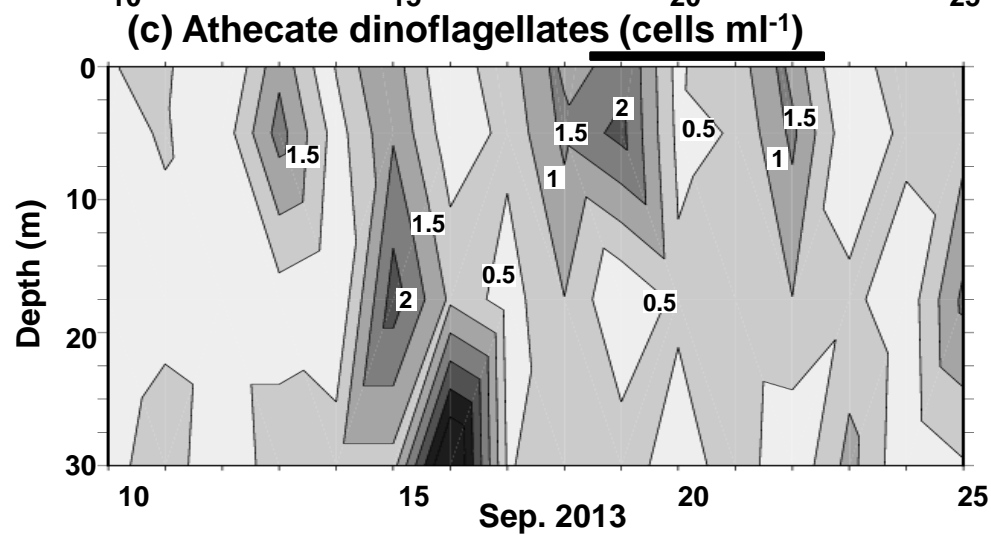
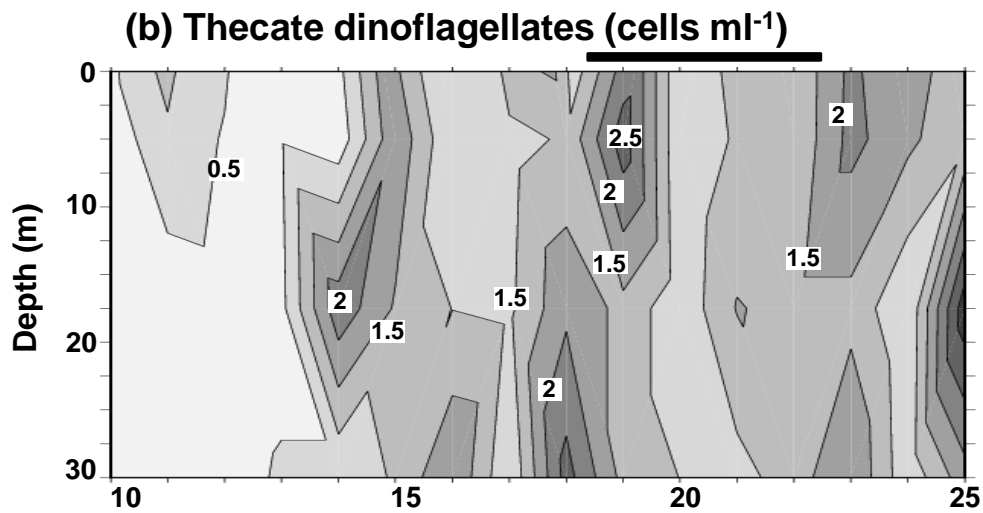
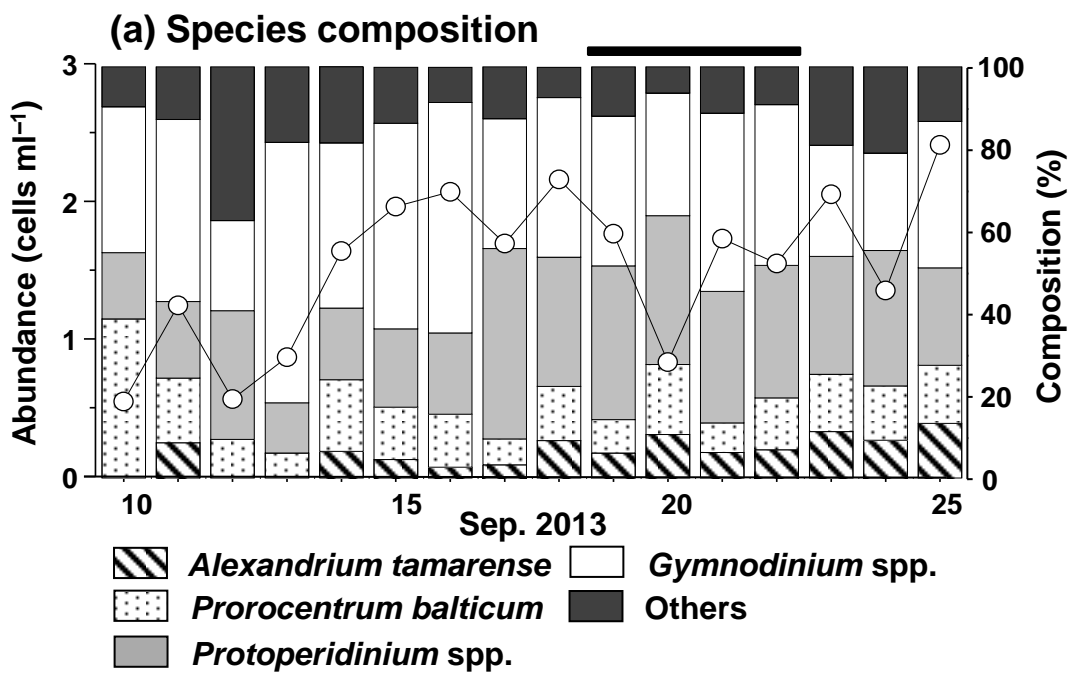


Fig. 4. (Yokoi et al.)

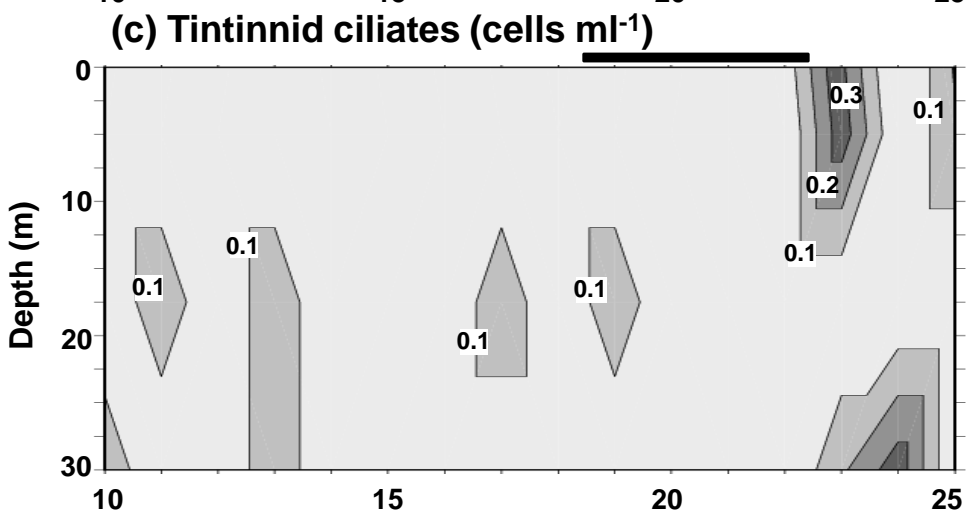
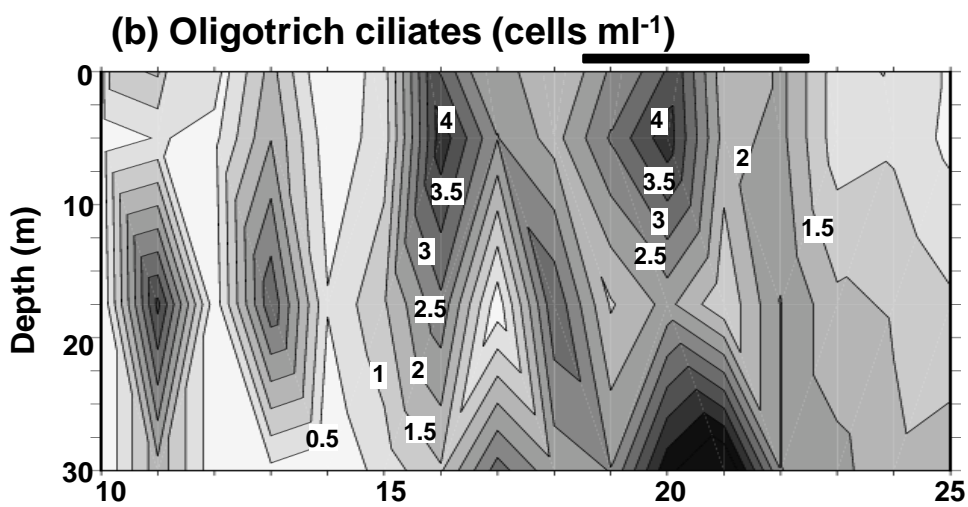
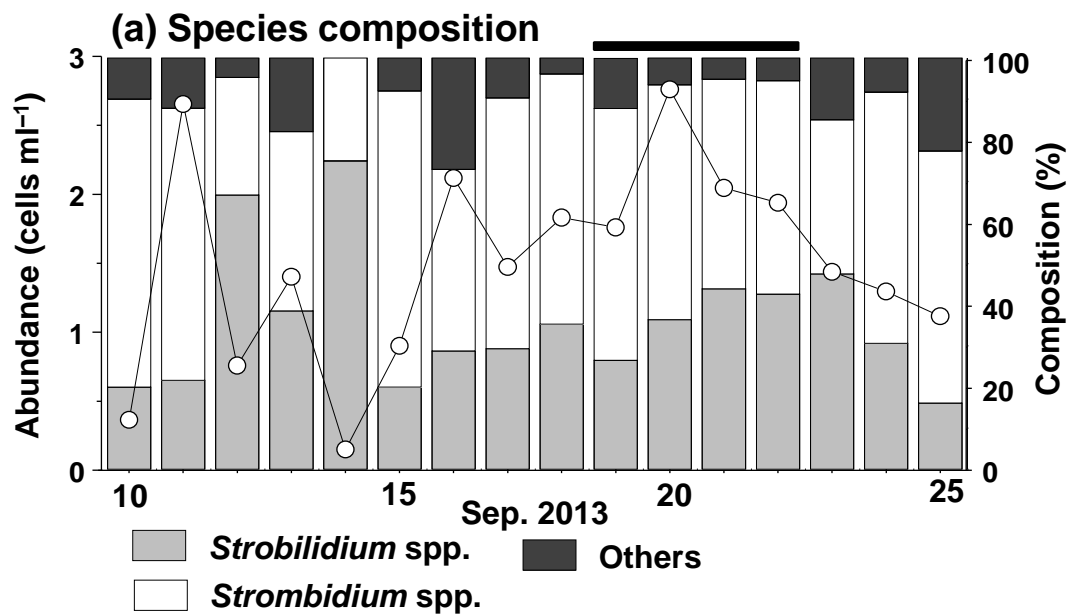


Fig. 5. (Yokoi et al.)

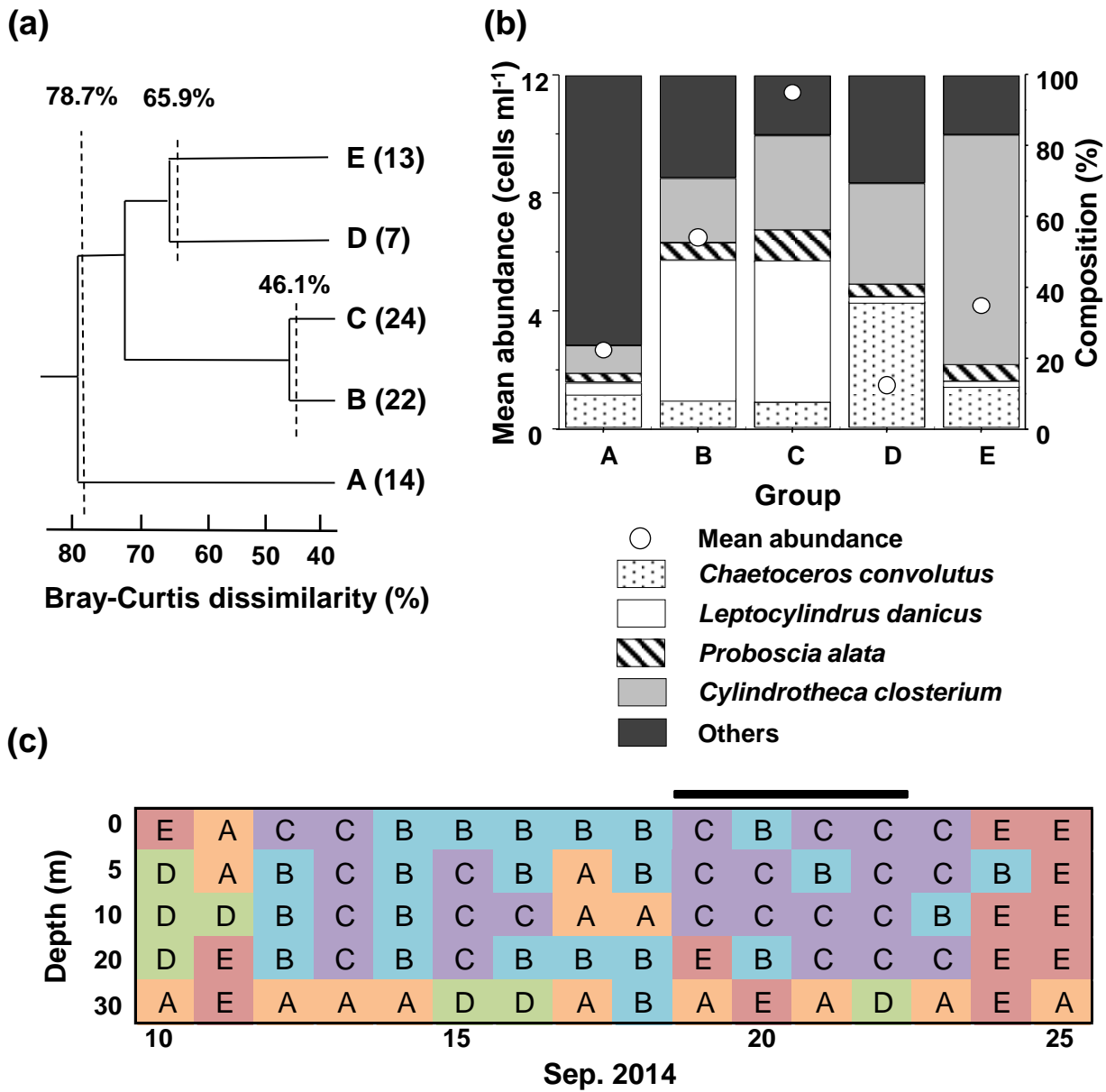


Fig. 6. (Yokoi et al.)

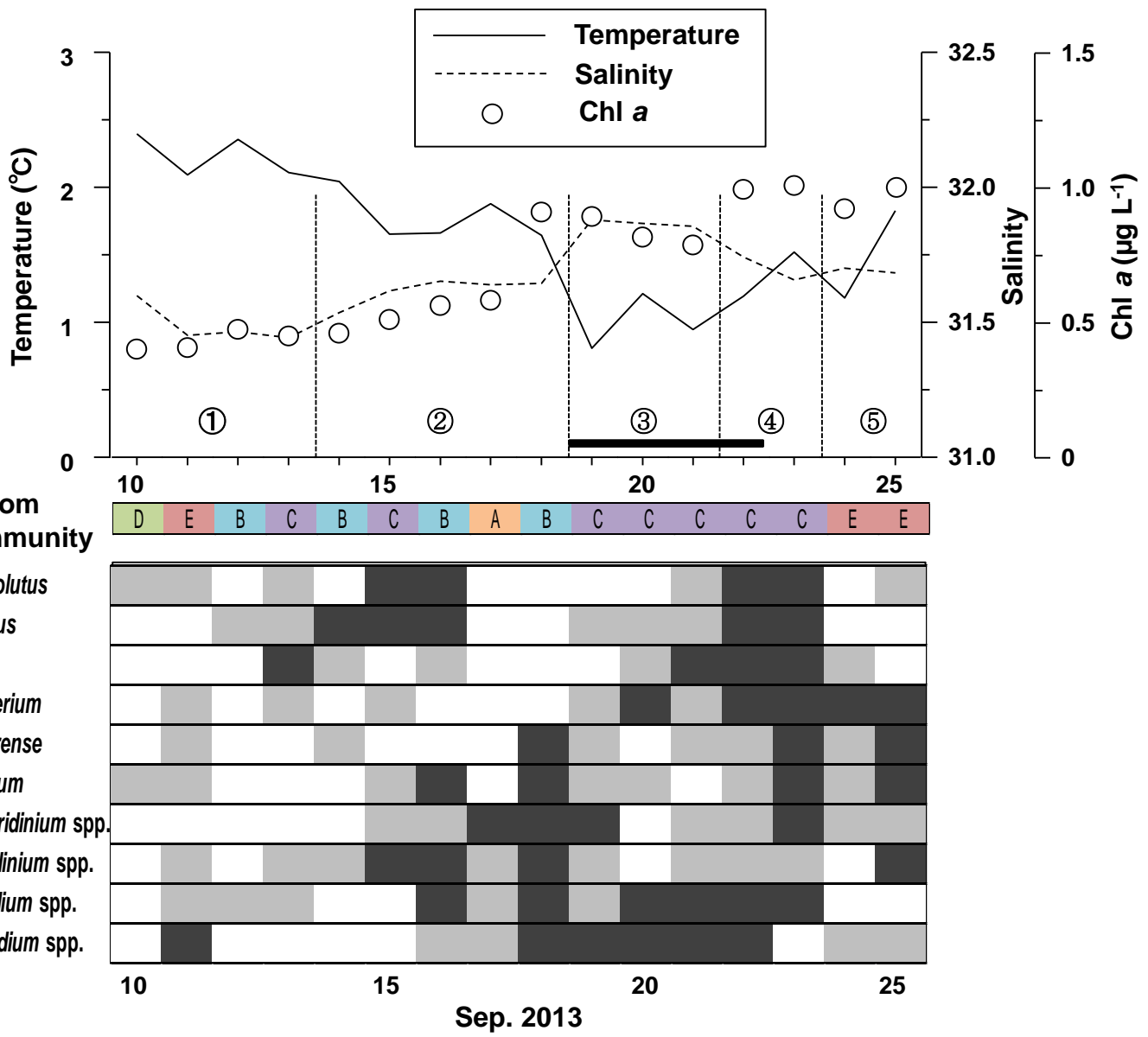


Fig. 7. (Yokoi et al.)