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The adaptation of Arctic phytoplankton to low light and salinity in Kongsfjorden (Spitsbergen)

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Abstract The basic environmental variables and adaptability of phytoplankton communities to low light and salinity were studied using incubation experiments in Kongsfjorden, a high Arctic fjord of Spitsbergen, in late summer 2006. Chlorophyll *a* concentrations were steady or decreased slightly in darkness after one day or one week incubation. Chlorophyll *a* concentrations showed an initial decline when exposed to natural light after one week incubation in darkness, and then increased significantly. In a salinity experiment, the maximal growth rate was observed at a dilution ratio of 10%, however, higher dilution ratios (⩾40%) had an obvious negative effect on phytoplankton growth. We suggest that the phytoplankton communities in fjords in late summer are darkness adapted, and the inflow of glacial melt water is favorable for phytoplankton growth in the outer fjords where the influence of freshwater is limited.

Keywords **phytoplankton, light, salinity, Kongsfjorden, Arctic**

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0 Introduction

Ny-Ålesund, on the Brøgger peninsula at Kongsfjorden and affected by the North Atlantic warm current, is one of the warmest areas in the Arctic. It has a humid temperate climate, and the air temperature can be above 0℃ even during mid-winter. The air temperature at Ny-Ålesund has been observed to increase more quickly (0.68℃·10 a^{-1}) than in the rest of the Arctic[1]. It is an international monitoring site for the study of Arctic climate change in the coming decades.

Kongsfjorden is a semi-open glacial fjord on the western coast of Spitsbergen, and shares a common mouth with the adjacent shelf. It is influenced by the mild temperatures mediated by the inflow of transformed Atlantic water (AW), the colder and fresher Arctic-type water (ArW), as well as freshwater from glacial melt, glacial calving, and precipitation. Freshwater influx is highest in summer and co-occurs with a strong increase in sediment particle concentrations[2], and decrease in euphotic zone depth. The melt water discharge affects the salinity of surface waters up to 45 km from the glacial front, and up to 30 m in depth[3-5]. Kongsfjorden is also strongly influenced by the West Spitsbergen Current (WSC) of Atlantic origin, that transports relatively warm saline water (salinity >34.7) northwards. As a result, it is characterized by relatively mild temperatures compared with other Arctic locations at similar latitude. Wang et al.[6] also concluded that the AW current greatly affects the upper 40 m of the water column in the outer fjord. These processes will strongly influence phytoplankton growth and local community composition.

Light is a crucial factor controlling phytoplankton growth, and studies suggest that some Arctic phytoplankton have survival capability in winter[7-9]. With the increase in sea ice melt and the influx of fresh water, the salinities of the Arctic upper waters have obviously declined. A study in the Arctic fjords suggested that decreased salinity and increased sediment load are major determinants of surface

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microbial community composition and diversity[10]. Li et al.[11] revealed that picoplankton, being very small in size (<2 μm diameter), are likely to thrive as the Arctic Ocean freshens due to climate change. If these changes persist, they will speed up microbial processes[12]. In general, however, little research has been done, and none in Kongsfjorden. We conducted an experimental study at Ny-Ålesund to evaluate the adaptability of Arctic phytoplankton to light and salinity variations in Kongsfjorden. We expect to find out whether phytoplankton in fjord are adapted to darkness, and what will be the responses of the phytoplankton assemblage to the inflow of glacial melt waters.

1 Materials and methods

1.1 Environmental data and sample collection

Environmental data and water samples were collected along a transect in Kongsfjorden, a high Arctic fjord in Ny-Ålesund, Spitsbergen, in August 2006 (Figure 1). The salinity, photosynthetically active radiation (PAR), and chlorophyll *a* concentrations were measured using a SBE 19 plus CTD (Sea-Bird Electronics, Inc.). Water samples were collected in a 2.5 L Niskin water sampler at ~5 m depth. Samples were brought back to the Marine Laboratory (Ny-Ålesund) for experimental retreatment immediately. Glacial melt waters used for the salinity experiment were collected from melting water stream near Ny-Ålesund airport and placed on the platform outside the laboratory for one day, to remove large sediment grains before experimentation.

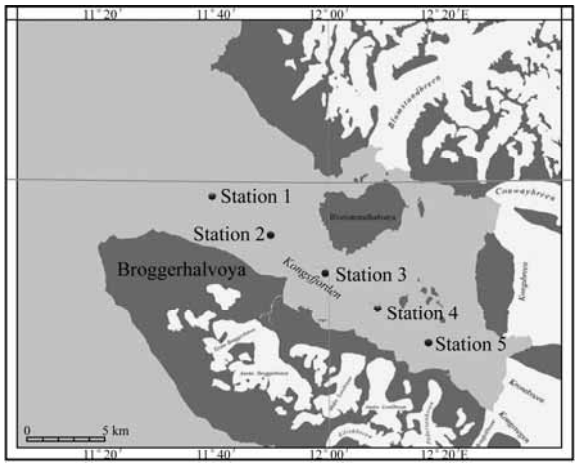

Figure 1 Sampling sites in Kongsfjorden, high Arctic.

1.2 Darkness adaption experiments

1.2.1 One day incubation experiment

Water samples were transferred to five Nelgene polycarbonate culture bottles (500 mL volume). Three parallel samples were covered with aluminum foil to maintain darkness and two were exposed to natural light during incubation at a local site (near the wharf). After one day of incubation, each bottle was rotated so the water sample could be mixed completely and 200 mL of subsample was collected for chlorophyll *a* concentration measurements.

1.2.2 Ten days incubation experiment

Two parallel samples were prepared for each experiment. In the first stage, they were incubated in the incubator at the Marine laboratory (Ny-Ålesund) and kept in complete darkness. The incubator waters were pumped from the fjord (at about 70 m depth, using laboratory pumping system), so the temperature was similar to the water *in situ*. After one week of incubation, a 100 mL subsample was collected for chlorophyll *a* measurement. The bottles were moved to the water near the wharf and incubated for a further three days. After one day incubation and the end of the incubation (3 d), 100 mL and 200 mL subsamples were collected, respectively, for chlorophyll *a* measurement.

1.3 Salinity experiments

Seawater samples were collected at Stations 1 and 4. The series dilution rates of sea water and melting water were: 100%, 90%, 80%, 60%, 40% and 20%. Three parallel samples were made for each experiment. Cultures were placed near the wharf for one day and a 200 mL subsample was collected from each bottle and chlorophyll *a* concentrations were measured.

1.4 Chlorophyll *a* concentration measurements

Each subsample was filtered through a 47 mm diameter Waterman GF/F filter and extracted in 90% acetone for 24 h in a low temperature environment. Chlorophyll *a* concentration was determined fluorometrically, following the method of Parsons et al.[13].

1.5 Phytoplankton growth rate calculation

Phytoplankton growth rates were calculated using the following formula:

$$\mu = \ln(N_t/N_0)/t$$

where μ is the growth rate, N_t is the phytoplankton biomass (chlorophyll *a* concentration) after incubation, N_0 is the phytoplankton biomass at the beginning of incubation, and t is the incubation time (d).

2 Results

2.1 The environment during the experimental period

Figure 2 shows the profiles of salinity, PAR, and chlorophyll *a* concentrations in the upper 50 m of the water column at five stations. Salinities decreased with depth and a marked halocline occurred in the water column. At 5 m depth, the salinity decreased from 32.22 at Station 1 to 31.43 at Station 4. The light attenuated quickly in the upper water column and the PAR at 10 m depth was less than 10% of that in the surface water. The turbidity was higher in the inner fjord (Stations 4 and 5) than in the outer fjord

(Stations 1 and 2). The depths of the euphotic zone were between 25 m and 30 m, with a decrease from the outer to inner fjord. The maximum chlorophyll *a* concentrations were observed at 10 m—15 m except for Station 1, where the maximum occurred at 20 m depth.

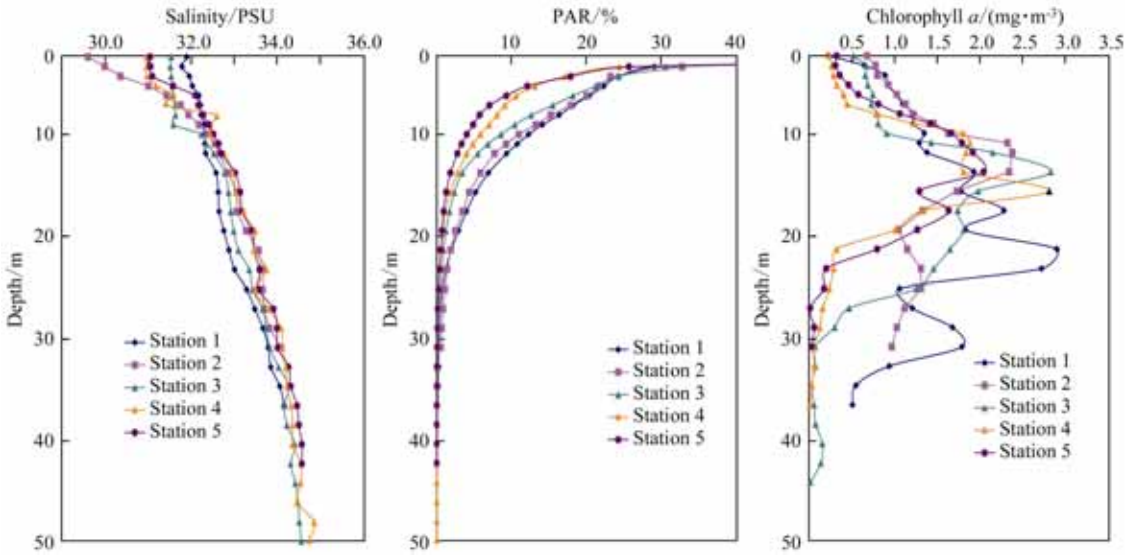

Figure 2 Profiles of salinity, PAR, and chlorophyll *a* concentrations in the upper 50 m of the water column.

2.2 Darkness experiments

In the one day darkness experiment, no significant difference in mean chlorophyll *a* concentrations occurred between light and dark treatments after incubation, suggesting that these phytoplankton communities have the ability to adapt to darkness. At Stations 1 and 2 in the outer fjord, the growth rates (-0.04 and 0.03, respectively) in light conditions were higher than in darkened conditions (-0.31 and -0.10, respectively). In the inner fjord, however, there were no significant differences in growth rate between light and dark treatments (Table 1). Figure 3 shows the ratio of chlorophyll *a* concentrations in light and darkness after one day incubation at various stations, suggesting that there is increasing phytoplankton growth from the inner to the outer fjord.

Table 1 Comparison of phytoplankton growth in light anddarkness (n=number of samples) after one day incubation

Station Number	Dark			Light		
	chlorophyll *a* /(mg·m^{-3})	pro Chl *a*	growth rate	chlorophyll *a* /(mg·m^{-3})	pro Chl *a*	growth rate
1	0.717 (*n*=3)	0.97	-0.31	0.930 (*n*=2)	0.97	-0.04
2	0.833 (*n*=3)	0.92	-0.1	0.960 (*n*=2)	0.92	0.03
3	0.603 (*n*=3)	-	-	0.620 (*n*=2)	-	-
4	0.867 (*n*=3)	-	-	0.830 (*n*=2)	-	-

Notes: -: no data; pro Chl *a*: chlorophyll *a* concentration before incubation.

In our second experiment, no significant changes in mean chlorophyll *a* concentrations were found after incubation for one week. Chlorophyll *a* concentrations showed an initial decrease when exposed to natural light, after which chlorophyll *a* started to increase significantly (Figure 4). At Station 2, the growth rate varied from 0.029 in the 7 d darkened condition, to -0.126 in the 1 d and 0.885 in the 2 d light condition. However, at Station 4, the growth rate varied from -0.003 in the 7 d darkened condition, to -0.042 in the 1 d and 0.163 in the 2 d light condition.

2.3 Salinity experiments

Figure 5 shows the parabola-like salinity dependence of the specific growth rate of phytoplankton at *in situ* seawater temperature under natural light. The maximal mean growth rate was at a dilution ratio of 10% and decreased continuously from this optimum toward higher or lower salinities. Surprisingly, at the highest salinity (dilution ratio, 0), the mean growth rate was significantly higher than at a dilution ratio of 80%, at which the minimal value was obtained. At

Station 2, when the dilution ratio was 60%, the phytoplankton growth rate was similar to the undiluted sample; however, it was 20% at Station 4. This may reflect an decreased salinity from the outer to inner fjord, influenced by glacial melt.

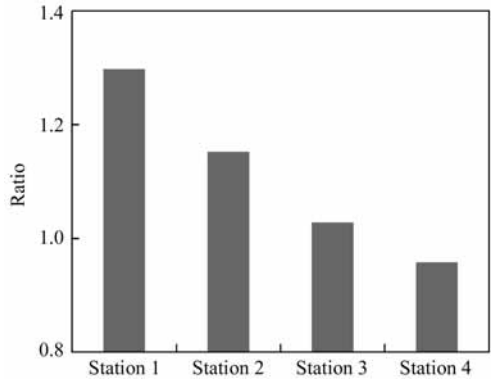

Figure 3 Ratios of Chlorophyll *a* concentrations in light and darkness after one day incubation at various stations.

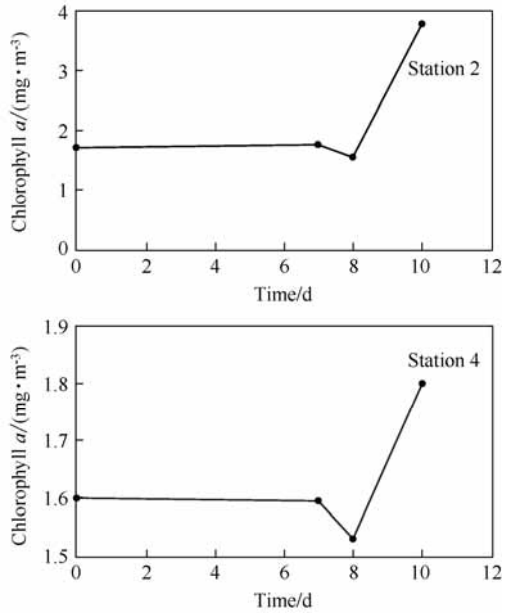

Figure 4 Temporal variation in chlorophyll *a* concentration in the light-dark conversion experiment.

3 Discussion

3.1 The adaptability of phytoplankton to darkness

It has been reported that the phytoplankton in high latitude regions show fundamentally shade-adapted features[7]. Our results concur with those of previous studies, suggesting that the phytoplankton community can survive without irradiance. A study in the central Arctic Ocean showed that a 2 mm diameter *micromonad* was present (among other phytoplankton) in epifluorescence counts throughout the winter darkness, and represented a major constituent of the spring bloom beneath the pack ice[8]. Continuous seasonal observations have also shown the ability of phytoplankton to retain pigments and survive throughout winter darkness at reduced population densities; and to resume exponential population growth at the earliest return of light in late winter-early spring[9]. Mixotrophy, the use of both phototrophic and heterotrophic strategies for energy acquisition, could be one mechanism allowing this and other phytoplankton to survive under this low-energy regime. Mixotrophy is common in marine and freshwater phytoplankton and numerous studies (many of them in continental waters) highlight its importance in polar environment[14-15]. Presumably, the dark survival of haptophytes[7] and other under-ice microalgae endowed with prominent chloroplasts may have been aided by mixotrophy[16]; this may include osmotrophy (uptake of dissolved organic matter) or phagotrophy (engulfment of organic particles).

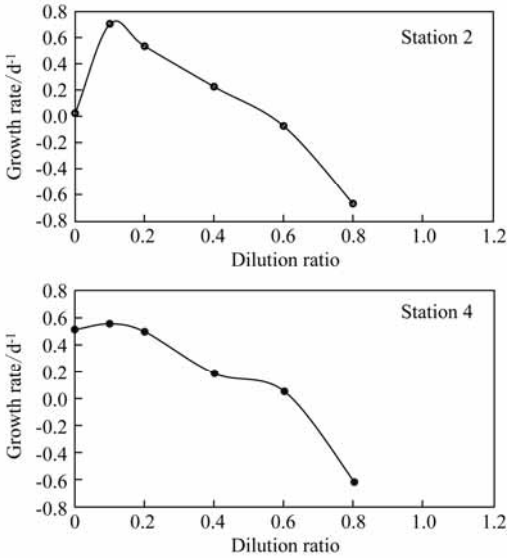

Figure 5 Growth rate of phytoplankton under different dilutions in salinity experiments.

Figure 4 suggests that phytoplankton community in Station 2 has a better dark-adapted ability than those in Station 4. This may be responsible for different phytoplankton community composition and biomass between Stations 2 and 4. Wang et al.[6] revealed different environmental and biotic data between the surface layers of the inner and outer fjords. The biomass of heterotrophic nanoflagellates was significantly higher in the surface waters of outer Kongsfjorden than in the other water masses[6]. Diatoms are known to be the most substantial contributors to phytoplankton biomass in outer basins, whereas autotrophic dinoflagellates are abundant and most diverse in inner fjord[17-18]. In August 2006, the development of phytoplankton in the inner fjord appeared to be stressed by glacial melt water inflow. High sediment load is known to result in poor light conditions in the inner fjord[19]; this explains the lower chlorophyll *a* concentration (1.6 mg·m^{-3}) at Station 4 than at Station 2 (1.8 mg·m^{-3}). The initial decrease suggests the potentially deleterious effects of light on

shade-adapted organisms. The light-shade acclimation of psychrophilic phytoplankton in polar oceans has been reported[20-23]. It has also been observed that in psychrophilic phytoplankton, a shift from low light to high light caused a decrease in photosynthetic efficiency[19].

3.2 Effect of salinity on phytoplankton growth

Fredersdorf et al.[24] showed that an arctic marine macroalgae, *Alaria esculenta* (Phaeophyceae) was relatively tolerant of and adaptable to diluted salinities, but only up to specific limits. Some studies[25-26] have demonstrated that salinity has a strong influence on the growth of Arctic and Antarctic ice algae and on changes in community composition. It seems that sea-ice algae are tolerant of decreased salinities to some extent[27]. Whether the arctic phytoplankton community is tolerant of lower salinity deserves further study.

Growth estimates for phytoplankton communities vary among stations in the outer and inner fjords. This may be explained by the different phytoplankton community composition at the stations, although we did not study the initial phytoplankton community composition and its change after incubation at different salinities. Kongsfjorden is a small fjord with a wide opening to the open ocean via Kongsfjordrenna. A sill in the middle of the fjord divides it into an outer part, strongly influenced by West Spitsbergen Current, and an inner part influenced by glaciers: Kronebreen, Kongsvegen, Conwaybreen and Blomstrandbreen[4]. The complex dynamics of the fjord's water masses may be regarded as the major driving forces for the variability in phytoplankton assemblages. Diatoms are the most substantial contributors to phytoplankton biomass, especially in outer basins, whereas autotrophic dinoflagellates are the most important contributors in the inner fjord[17-18]. A study showed a dominance of dinoflagellates and the chrysophyte *Dinobryon Balticum* in the surface layers, whereas the abundance of diatoms and the haptophyte *Phaecystis pouchetii* increased with depth, and some *Nitzschia* species found in the plankton samples are usually regarded as typical sea-ice diatoms[28]. Microscopic and genetic analyses suggested that significant biodiversity of dinoflagellates occurred during the summer 2006 in Kongsfjorden[29].

Figure 5 shows that the growth rates with lower dilution (0%—20%) at Station 4 were more stable than those at Station 2. This may reflect andecreased salinity from the outer to the inner fjord influenced by glacial melt, and the community in the outer fjord was more sensitive to the freshwater inflow than the inner fjord. Wang et al.[6] also concluded that the salinity of the surface water (average 31.5) throughout the transect was low, and lower in the inner fjord because of glacial melt. There are several possible reasons for the variation in observed growth rates of the phytoplankton as a response to different salinities consequent from addition of different melt water. Melt water addition caused decreased grazing pressure[30], which can stimulate phytoplankton growth. However, we did not exclude grazers in melt water from our experiment by pre-screening, and thus grazers such as heterotrophic flagellates, ciliates, and metazoans were present in our samples. Additionally, enclosure itself may have also affected the growth of phytoplankton. As with all incubations, enclosure of the planktonic community may have affected a variety of other factors in addition to the variables manipulated in the treatments. These other factors may include exchanges of materials and increased grazing pressure. We have assumed that grazing will not have significantly affected the determined growth rate.

A further artifact might be introduced by changing the nutrient regime, because the nutrient status varied between the different salinity treatments due to the mixture of varying amounts of melted glacial water and high saline seawater at the beginning of the experiments. The melting water generates increased nutrients and leads to an initial slight increase in nutrient availability for the phytoplankton. Andersen and Prieur[31] reported that wind-forcing enhanced availability of nitrate in the euphotic layer, a drastic decrease in phytoplankton biomass, and the processes (vertical advection, primary production, grazing pressure, etc.) controlling this decrease. In addition, the incubation time was just one day, thus nutrients did not became a limiting factor for phytoplankton growth. Some studies have indicated that the input of melt water induced higher phytoplankton growth, although significantly lower concentrations of nutrients were observed in melting-affected waters[32]. In contrast, dilution brings about lower light penetration and decreased salinity and these may have negative effects on growth. From our darkness adaptation experiment, we concluded that the phytoplankton community has good shade-adapted ability to survive, so lower irradiance is not an inhibiting factor for phytoplankton growth.

When the melt rate was higher (~80%), the growth rate decreased rapidly to its lowest. This suggests salinity is an important ecological factor that superimposes effects on the growth of phytoplankton, comparable to grazing pressure, light penetration, and nutrients. Besides this uncertainty, our study was carried out in the context of an extremely high load of melt water entering the Kongsfjorden, which provided an opportunity to study the growth of phytoplankton in conditions that will probably occur again in future. We chose our experimental approach because it simulates precisely the natural ongoing processes leading to salinity variations. Large amounts of melted water entering the ocean reduces the salinity and temperature of the surface water and can be an additional source of microorganisms, contaminants, and organic carbon[33-36].

4 Conclusion

We report a good adaptability of phytoplankton to low irradiance in Kongsfjorden. To some extent, phytoplankton growth was promoted by low-to-moderate decreased salinity, but was strongly limited by lower salinity. This suggests an existing balance of phytoplankton in Kongsfjorden

that will be threatened with flowing melt water consequent from global warming. Further study should focus on the changes in phytoplankton community composition as a response to changing salinity and light.

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References

1 Deng H B, Lu L H, Bian L G. Short-term Climate Characteristics at Ny-Ålesund over the Arctic Tundra Area. Chinese Journal of Polar Science, 2005, 16(2): 109-120.
2 Somerfield P J, Cochrane S J, Dahle S, et al. Free-living nematodes and macrobenthos in a high-latitude glacial fjord. J Exp Mar Biol Ecol, 2006, 330: 284-296.
3 Keck A, Wiktor J, Hapter R, et al. Phytoplankton assemblages related to physical gradients in an arctic, glacier-fed fjord in summer. ICES J Mar Sci, 2001, 56: 203-214.
4 Hop H, Falk-Peterson S, Svendsen H, et al. Physical and biological characteristics of the pelagic system across Fram Strait to Kongsfjorden. Prog Oceanogr, 2006, 71: 182-231.
5 Svendsen H, Beszczynska-Møller A, Hagen J O, et al. The physical environment of the Kongsfjorden-Krossfjorden, an arctic fjord system in Svalbard. Polar Res, 2002, 21: 133-166.
6 Wang G, Guo C, Luo W, et al. The distribution of picoplankton and nanoplankton in Kongsfjorden, Svalbard during late summer 2006. Polar Biol, 2009, 32: 1233-1238.
7 Ban A, Aikawa S, Hattori H, et al. Comparative analysis of photosynthetic properties in ice algae and phytoplankton inhabiting Franklin Bay, the Canadian Arctic, with those in mesophilic diatoms during CASES (2003-3004). Polar Biosci, 2006, 19: 11-28.
8 Sherr E B, Sherr B F, Wheeler P A, et al. Temporal and spatial variation in stocks of autotrophic and heterotrophic microbes in the upper water column of the central Arctic Ocean. Deep-Sea Res I, 2003, 50: 557-571.
9 Lovejoy C, Vincent W F, Bonilla S, et al. Distribution, phylogeny and growth of cold-adapted picoprasinophytes in Arctic Seas. J Phycol, 2007, 43: 78-89.
10 Piquet M T, Scheepen J F, Bolhuis H, et al. Variability of protistan and bacterial communities in two Arctic fjords (Spitsbergen). Polar Biol, 2010, 33(11): 1521-1536.
11 Li W K W, Mclaughlin F A, Lovejoy C, et al. Smallest algae thrive as the Arctic Ocean freshens. Science, 2009, 326: 539.
12 Vincent W F. Microbial ecosystems responses to rapid climate change in the Arctic. The ISME Journal, 2010, 4: 1089-1091.
13 Parsons T R, Maita Y, Lalli C M. A manual of chemical and biological methods for seawater analysis. Oxford: Pergamon Press, 1984.
14 Horner R, Alexander V. Algal populations in Arctic sea ice: an investigation of heterotrophy. Limnol Oceanogr, 1972, 17: 454-458.
15 Laybourn-Parry J, Marshall W A. Photosynthesis, mixotrophy and microbial plankton dynamics in two high Arctic lakes during summer. Polar Biol, 2003, 26: 517-524.
16 Jones H L J, Leadbeater B S C, Green J C. Mixotrophy in haptophytes // Green C, Leadbeater B S C. The haptophyte algae. Oxford: Clarendon Press, 1994: 247-263.
17 Piwosz K, Walkusz W, Hapter R, et al. Comparison of productivity and phytoplankton in a warm (Kongsfjorden) and a cold (Hornsund) Spitsbergen fjord in mid-summer 2002. Polar Biol, 2009, 32:549-559.
18 Okolodkov Y B, Hapter R, Semovski S V. Phytoplankton in Kongsfjorden, Spitsbergen, July 1996. Sarsia, 2000, 85: 345-352.
19 Wiktor J. Early spring microplankton development under fast ice covered fjords of Svalbard, Arctic. Oceanologia, 1999, 41: 51-72.
20 Ikeya T, Kashino Y, Kudoh S, et al. Acclimation of photosynthetic properties in psychrophilic diatom isolates under different light intensities. Polar Biosci, 2000, 13: 43-54.
21 Lizotte M P, Sullivan C W. Rates of photoadaptation in sea ice diatoms from McMurdo Sound, Antarctica. J Phycol, 1991, 27: 367-373.
22 McMinn A, Hegseth E N. Quantum yield and photosynthetic parameters of marine microalgae from the southern Arctic Ocean, Svalbard. J Mar Biol Ass UK, 2004, 84(5): 865-871.
23 Michel C, Legendre L, Demers S, et al. Photoadaptation of sea-ice microalgae in springtime: photosynthesis and carboxylating enzymes. Mar Ecol Prog Ser, 1988, 50: 177-185.
24 Fredersdorf J, Mülle R, Becker S, et al. Interactive effects of radiation, temperature and salinity on different life history stages of the Arctic kelp Alaria esculenta (Phaeophyceae). Oecologia, 2009, 160: 483-492.
25 Zhang Q, Gradinger R, Spindler M. Experimental study on the effect of salinity on growth rates of Arctic-sea-ice algae from the Greenland Sea. Boreal Environ Res, 1999, 4: 1-8.
26 Ryan K G, Ralph P, McMinn A. Acclimation of Antarctic bottom-ice algal communities to lowered salinities during melting. Polar Biol, 2004, 27: 679-686.
27 Kirst G O, Wiencke C. Ecophysiology of polar algae. J Phycol, 1995, 31:181-199.
28 Hasle G R, Heimdal B R. The net phytoplankton in Kongsfjorden, Svalbard, July 1988, with general remarks on species composition of arctic phytoplankton. Polar Res,1998, 17(1): 31-52.
29 Luo W, Dai C, Li H, et al. Phylogenetic diversity of dinoflagellates in polar regions. Advances in Polar Science, 2011, 1: 35-41.
30 Landry M R, Hasset R P. Estimating the grazing impact of marine microzooplankton. Mar Biol, 1982, 67: 283-286.
31 Andersen V, Prieur L. One-month study in the open NW Mediterranean Sea (DYNAPROC) experiment, May 1995: overview of the hydrobiogeochemical structures and effects of wind events. Deep-Sea Res I, 1999, 47: 397-422.
32 Boras J A, Sala M M, Arrieta J M, et al. Effect of ice melting on bacterial carbon fluxes channeled by viruses and protists in the Arctic Ocean. Polar Biol, 2011, 33(12): 1695-1707.
33 Thomas D N, Dieckmann G S. Antarctic sea ice-a habitat for extremophiles. Science, 2002, 295: 641-644.
34 Pfirman S L, Eicken H, Bauch D, et al. The potential transport of pollutants by Arctic sea ice. Sci Total Environ, 1995, 159: 129-146.
35 Maranger R, Bird D F, Juniper S K. Viral and bacterial dynamics in Arctic sea ice during the spring algal bloom near Resolute, N.W.T., Canada. Mar Ecol Prog Ser, 1994, 111: 121-127.
36 Krembs C, Eicken H, Junge K, et al. High concentrations of exopolymeric substances in Arctic winter sea ice: implications for the polar ocean carbon cycle and cryoprotection of diatoms. Deep-Sea Res I, 2002, 49: 2163-2181.