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Scientific Paper

PRIMARY PRODUCTION OF PHYTOPLANKTON IN HIGH ARCTIC KONGSFJORDEN, SVALBARD

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Abstract: Standing stock and primary productivity of phytoplankton were investigated in relation to the environmental conditions in high arctic Kongsfjorden, Svalbard (Norway) during the early summer of 1993, just after the sea ice melting. The concentration of chlorophyll *a* in the surface water showed high values only during sea ice melting (1.0–5.7 $\mu g \cdot l^{-1}$), then decreased to less than 0.5 $\mu g \cdot l^{-1}$. Daily variations of photosynthetically active radiation (PAR) ranged from 200 to 1200 $\mu mole \cdot m^{-2} \cdot s^{-1}$ during the study period. Even in the midnight sun, more than 20% of the daily maximum PAR was recorded. Photosynthetic activity of phytoplankton measured by the ^{13}C stable isotope method was high (1.17 mg C·mg Chl. $a^{-1} \cdot hr^{-1}$) during the ice melting period, whereas that in the succeeding period was low (0.45 mg C·mg Chl. $a^{-1} \cdot hr^{-1}$). Daily primary production was calculated in the ice melting period and succeeding period to be 1100 and 87–119 mg $C \cdot m^{-2} \cdot day^{-1}$, respectively.

1. Introduction

Kongsfjorden is a high arctic fjord lying at about 79°N and 12°E on the west coast of Spitsbergen Island, Svalbard. The area has midnight sun from the middle of April to the end of August (HALLDAL and HALLDAL, 1973). Even at such a high latitude, sea ice covering the fjord disappears in summer. The melting of sea ice produces a relatively low salinity, shallow surface layer which enhances stratification of the water column. Water column stability is one of the major factors for elevated production and high standing crop of phytoplankton in polar waters especially near and/or under sea ice (LEGENDRE *et al.*, 1981; SMITH and NELSON, 1985; NIEBAUER and ALEXANDER, 1985). Phytoplankton and hydrographic conditions in the high arctic ice edge area, however, are still fairly well known.

In the framework of the International Scientific Research Program "Biological Processes in the Arctic Polynya Areas", small scale experiments were conducted to obtain the standing stock and photosynthetic activity of phytoplankton in Kongsfjorden in the early summer of 1993. This paper presents variations of concentration of chlorophyll *a* and photosynthetic activity of phytoplankton as well as hydrographic conditions and photosynthetically active radiation during the course of sea ice melting. Based on these

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data, primary productivity of phytoplankton in Kongsfjorden in early summer was evaluated.

2. Materials and Methods

Field studies were conducted in May and June 1993 at two stations in Kongsfjorden (Fig. 1) just after the sea ice melting. Because there were many floating fragments of sea ice, water was only sampled from the surface down to 10 m depth at the near shore station (St. 2) off Ny-Ålesund Base in May. In June, after sea ice had disappeared in the fjord, sampling was conducted from the surface down to 100 m with a 6 liter Van-Dorn sampler both in the central part of the fjord, St. 1 (78°56′N, 12°02′E) and at St. 2.

A part of water samples, 200 to 500 m*l*, was filtered with glass fiber filters (Whatman GF/F). Immediately after the filtration, the filters were kept in poly-carbonate tubes with 6 ml of N,N-dimethylformamide (SUZUKI and ISHIMARU, 1990) and stored in the dark for extraction of pigments. Concentrations of chlorophyll *a* and phaeopigments were determined fluorometrically (PARSONS *et al.*, 1984) with a Turner Designs fluorometer Model 10AU-005R.

The rest of the water samples were used to measure the photosynthetic activity of phytoplankton under various light conditions by the light-and-dark-bottle method with the ^{13}C stable isotope (SATOH *et al.*, 1985). The gradient of light intensity was adjusted with nylon-cloth screens. The amounts of photosynthesis taking place in each layer in the water column were estimated by the chlorophyll method (ICHIMURA *et al.*, 1962) using the data of standing stocks, photosynthetic activity of phytoplankton and the light intensity. For this calculation, daily variations of incident and underwater photosynthetically active radiation (PAR) were monitored with a LI-1000 quantum recorder with LI-190SB and LI-192SB quantum sensors (LI-COR, USA), respectively. Daily total production within the water column was calculated from the vertical profiles of photosynthesis taking place in each layer by graphic integration.

Vertical profiles of water temperature and salinity were recorded by AST-1000 STD profiler (Alec Electronics, Japan).

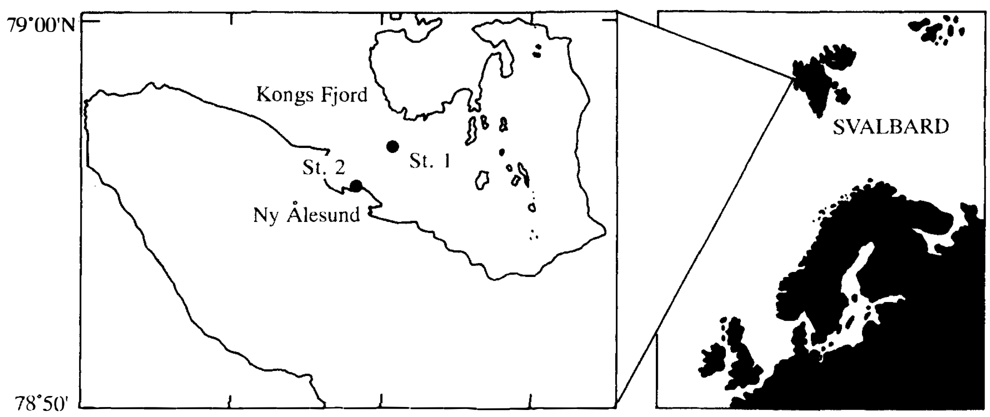

Fig. 1. Map of Kongsfjorden showing the sampling stations .

3. Results and Discussion

3.1. Hydrography

Kongsfjorden remained covered with ice until the beginning of May 1993, and it started to melt in mid-May. After the sea ice melted, the surface water of the fjord was warmed rapidly and a remarkable thermocline was formed at around 10 m depth. Typical hydrographical profiles of water temperature and salinity measured at St. 1 after the melting of sea ice are shown in Fig. 2. Maximum water temperature, 3.15°C, was recorded at 2.5 m depth, and it decreased sharply to 0.75°C at 12 m depth. Another small thermocline was observed at around 70 m depth where the water temperature was below 0°C. The gradient of water temperature in the middle layer between the two thermoclines was very small (0.013°C·m^{-1}) .

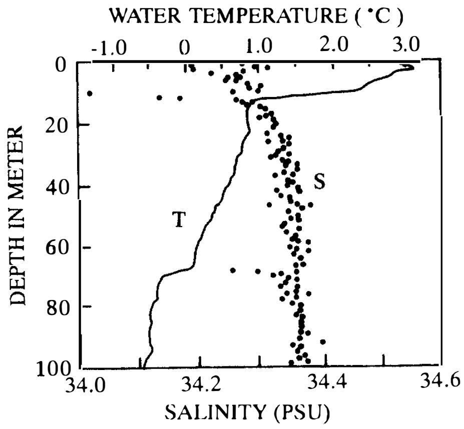

Fig. 2. Typical vertical profiles of water temperature (T) and salinity (S) at St. 1 in Kongsfjorden on June 3 after the sea ice melting.

Salinity in the surface layer was less than 34.3 PSU and fluctuated largely due to the influence of fresh water inflowing from the surrounding area. Below the upper thermocline, salinity varied around 34.35 PSU.

From these hydrographical profiles, we can recognize three major water masses vertically in the central part of the fjord. They correspod to those of surface, intermediate and Atlantic waters of the scheme described by WESLAWSKI *et al.* (1991).

3.2. Solar irradiance

Figure 3 shows daily changes of PAR recorded at Ny-Ålesund Base during the early summer in 1993. Daily maximum solar radiation on the fine and the cloudy days were in the ranges of 1100–1200 and 600–800 μmole·m^{-2}·s^{-1}, respectively. The level of solar radiation at around local noon under an overcast sky was about 55–67% of that under a clear sky. Even under the midnight sun, 150–400 μmole·m^{-2}·s^{-1} of solar radiation was recorded, corresponding to more than 20% of the maximum daily radiation.

The typical profiles of underwater PAR as well as concentration of chlorophyll *a* at St. 1 are plotted in Fig. 4. The attenuated light in the water column decreased rapidly with depth. If the relative light intensity at the compensation depth for phytoplankton photosynthesis is assumed to be 1% of the surface illumination, the euphotic depth in the central part of this fjord was calculated to be around 35 m in the observation period.

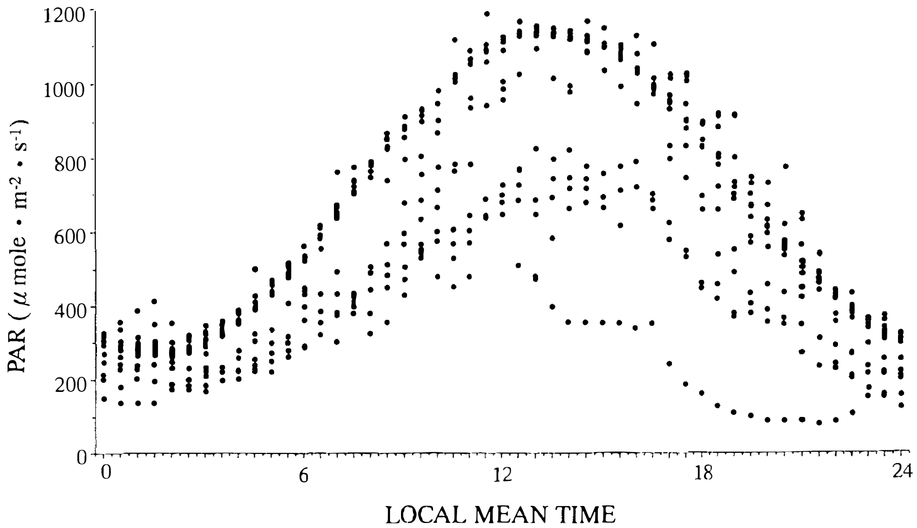

Fig. 3. Daily changes of incident radiation (PAR) at Ny-Ålesund from late May to early June in 1993.

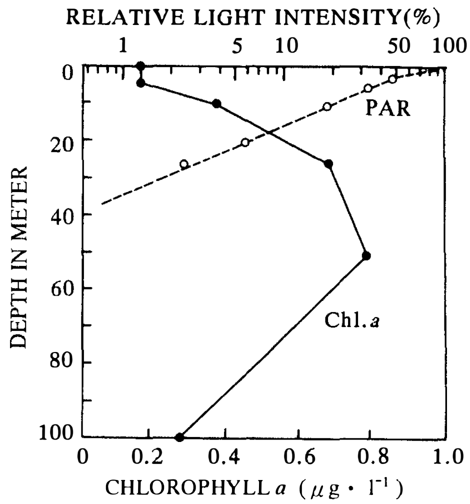

Fig. 4. Attenuation of PAR and the concentration of chlorophyll a *(Chl.* a*) at St. 1 in Kongsfjorden on June 12 after the sea ice melting.*

3.3. Standing stock of phytoplankton

The concentration of chlorophyll *a* in the surface water at St. 2 showed high values only during the course of sea ice melting (1.0–5.7 $\mu g \cdot l^{-1}$) then decreased sharply to less than 0.5 $\mu g \cdot l^{-1}$ (Fig. 5). In Dumbell Bay (82°30′N), Canadian Arctic, APOLLONIO (1980) reported a maximum value of phytoplankton chlorophyll *a* of 8.2 $\mu g \cdot l^{-1}$ just after the melting of sea ice. In Antarctic shelf areas, phytoplankton blooms up to 1.5 μg chlorophyll $a \cdot l^{-1}$ are common events and blooms in these waters commonly reach over 5 μg chlorophyll $a \cdot l^{-1}$ (*e.g.* EL-SAYED and TAGUCHI, 1981; SAKSHAUG and HOLM-HANSEN, 1984; SMITH and NELSON, 1985). In an ice covered lagoon, Saroma-ko, Hokkaido, FUKUCHI *et al.* (1989) also recorded a remarkable increase of phytoplankton chlorophyll *a* under the sea ice, which reached a maximum of 4–5 $\mu g \cdot l^{-1}$ just before the melting of sea ice and then declined to a low level. The same phenomenon was also reported by FUKUCHI *et al.* (1984) in the Antarctic fast ice area, where the maximum chlorophyll *a* concentration

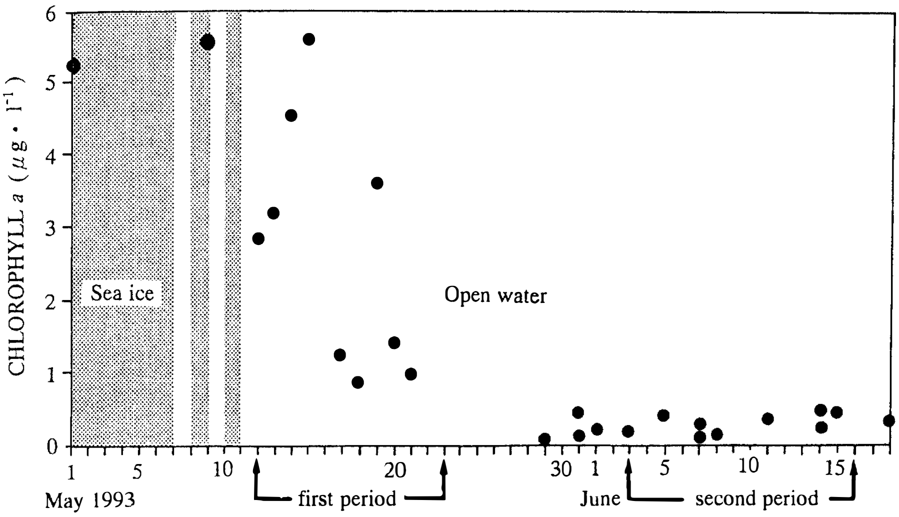

Fig. 5. Day to day variations of chlorophyll a *concentration in the surface water during the early summer at St. 2 off the Ny-Ålesund Base.*

recorded was as high as 11.3 $\mu g \cdot l^{-1}$. Considering these results, higher values of chlorophyll *a* obtained in the early period of the present study could be explained by the phytoplankton bloom caused by the increase of incident solar radiation just before and after the sea ice melting as described by LEGENDRE *et al.* (1981). The release of ice algae might also have contributed to some extent to increase the phytoplankton standing stock.

The rapid decrease of chlorophyll *a* in the succeeding period might have been caused by decrease of inorganic nutrients. The amounts of inorganic phosphate and ammonia in the surface water declined from 0.26 to 0.04 $\mu mole \cdot l^{-1}$ and from 0.36 to less than 0.01 $\mu mole \cdot l^{-1}$ within 8 days (from May 13 to May 21), respectively (MIYAHARA, 1993).

The profile of vertical distribution of chlorophyll *a* at St. 1 after sea ice melting is indicated in Fig. 4. A clear subsurface maxima of chlorophyll *a*, 4.6 times higher than that in the surface water, was observed at 50 m depth. The concentrations of chlorophyll *a* in the euphotic layer varied from 0.17 to 0.79 $\mu g \cdot l^{-1}$ and the integrated value from the surface down to 100 m was 28.6 $mg \cdot m^{-2}$. According to HALLDAL and HALLDAL (1973), the amount of chlorophyll *a* in Kongsfjorden during mid summer (July) ranged from 0.15 to 5.45 $\mu g \cdot l^{-1}$. In Antarctic and Sub-Antarctic waters, vertically integrated chlorophyll *a* over the euphotic layer ranges from 0.23 to 338 $mg \cdot m^{-2}$ with the average value of 17.4 $mg \cdot m^{-2}$ (EL-SAYED, 1970; EL-SAYED and TURNER, 1977; HOLM-HANSEN *et al.*, 1977). Comparing with these results, the amounts of chlorophyll *a* measured in the present study were rather small.

3.4. Photosynthetic activity and primary production of phytoplankton

Typical photosynthesis-light curves of phytoplankton measured by the ^{13}C method under natural light intensity is indicated in Fig. 6. The shape of the curves shows slight photo-inhibition (GOLDMAN *et al.*, 1963; ICHIMURA and ARUGA, 1964) . In the P. *vs* I. curves, the maximum rate of photosynthesis of surface phytoplankton at St. 2 on May 12 was 1.17 mg C·mg Chl. $a^{-1} \cdot hr^{-1}$ which was obtained under 79 $\mu mole \cdot m^{-2} \cdot s^{-1}$ (15% of the maximum incident radiation), whereas that obtained at St. 1 on June 12 was 0.45 mg

C·mg Chl. a^{-1}·hr^{-1} under 300 μmole·m^{-2}·s^{-1} correspoding to 25% of maximum incident radiation (Fig. 6 and Table 1). EILERTSEN *et al.* (1989) found that the chlorophyll-specific carbon uptake typically varied between 1.0 and 1.5 mg C·mg Chl. a^{-1}·hr^{-1} on the east side of Spitsbergen in the Arctic Barents Sea. In the Southern Ocean, NEORI and HOLM-HANSEN (1982) reported values ranging from 0.91 to 2.13 mg C·mg Chl. a^{-1}·hr^{-1} when incubations were conducted at *in situ* temperatures. Other studies have found values near 1.0 at low temperatures (*e.g.* HOLM-HANSEN *et al.*, 1977; LI, 1980; YAMAGUCHI *et al.*, 1985). Maximum rates of photosynthesis obtained in the present study were slightly lower than those reported in other studies.

Combining the P. *vs* I. curves with the data of concentrations of chlorophyll *a* and light regime on the typical fine and cloudy days, the amounts of primary production within one hour in each layer were firstly estimated. To calculate the daily rates of

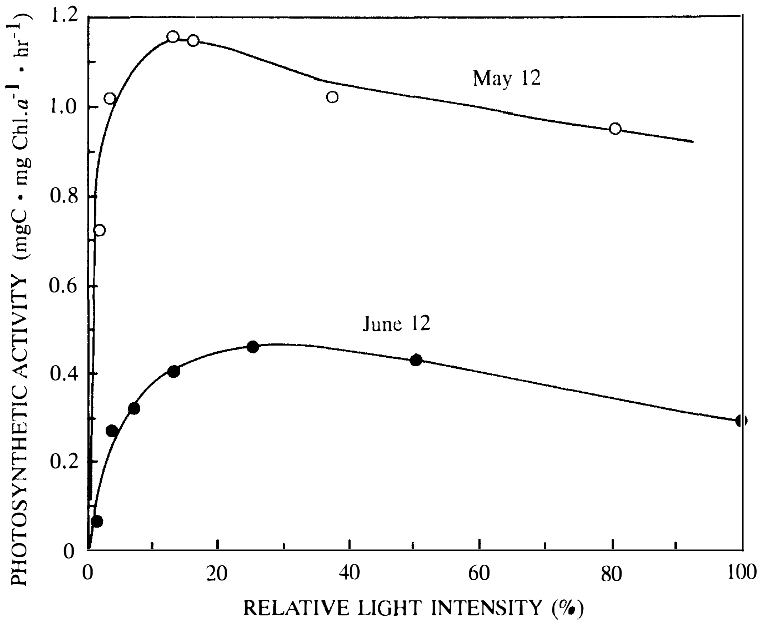

Fig. 6. Typical curves of photosynthesis vs light for phytoplankton in the surface water. Maximum light intensities under the 100% incident radiation were 527 μmole·m^{-2}·s^{-1} on May 12 and 1200 μmole·m^{-2}·s^{-1} on June 12, respectively.

Table 1. Concentration of chlorophyll a *(Chl.*a*; μg·l^{-1}), maximum photosynthetic activity (P_{max} ; mgC·mg Chl.*a*$^{-1}$·hr^{-1}) and estimated daily primary production (P.P.; mgC·m^{-2}·day^{-1}) in Kongsfjorden in early summer of 1993. F: fine day and C: cloudy day.*

Period	Chl. *a*	P_{max}	P. P.
May 12	2.8–8.4	1.17	1100
June 3–12	0.17–0.79	0.45	F : 119 C : 87.0

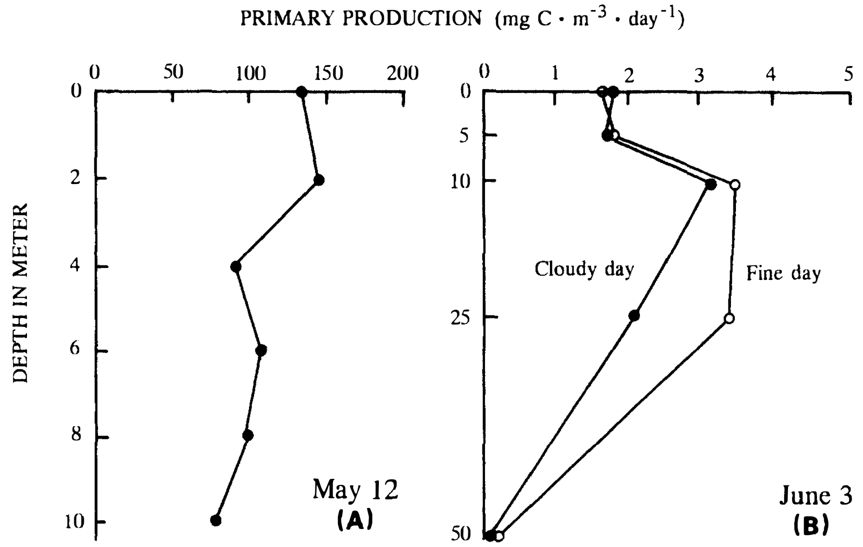

Fig. 7. Calculated daily primary production in Kongsfjorden. (A); At St. 2 off Ny-Ålesund Base on May 12, and (B); at St. 1 in the central part of Kongsfjorden on June 3 in 1993.

primary production in each layer, hourly rates of production were summed up for 24 hours. Depth-profiles of calculated daily production per unit volume of water in the water column in the two experimental periods are shown in Fig. 7. The rate of primary production at St. 2 was highest in the surface layer and decreased with increase of depth. On the other hand, primary production was rather low in the surface layer, exceedingly high in the upper intermediate water and decreased with depth in the second experimental period at St. 1. By graphical integration of the depth-profiles, total daily production within the euphotic layer was estimated (Table 1). As shown in the table, the calculated daily primary production in this fjord was high, 1100 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$, just after the sea ice melting (first experimental period), whereas those in the succeeding period (second experimental period) were only 119 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$ on fine days and 87.0 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$ on cloudy days, respectively. APOLLONIO (1980) reported that the daily gross and net production in Dumbell Bay, in the Canadian high Arctic, during mid summer were 40–172 and 14–96 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$, respectively. On the eastern side of Spitsbergen in the Barents Sea, integrated net carbon assimilation values within the surface waters were 311 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$ in July (20–80 m) and 291 mg $C{\cdot}m^{-2}{\cdot}day^{-1}$ in August (10–75 m), respectively (EILERTSEN *et al.*, 1989). SAKSHAUG and HOLM-HANSEN (1984) obtained the typical ranges for primary production in Arctic and Antarctic waters of 200–2500 and 50–4700 mg $C{\cdot}mg^{-1}{\cdot}day^{-1}$, respectively. Considering these reports, daily primary production obtained in the first period of the present study was not greatly different from those reported in other studies. However, it can be concluded that the level of primary production in mid summer in Kongsfjorden is rather low compared with those reported in Arctic and Antarctic offshore waters.

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