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Size Composition of Phytoplankton in the Western Subarctic Gyre in July 1997

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Size compositions (<2, 2-10 and >10 μ m) of phytoplankton biomass (chlorophyll *a* concentration) were investigated within the euphotic layer (100, 30, 10, and 1% light depths) in the Western Subarctic Gyre in July 1997. Mean concentrations of the total, <2, 2-10 and >10 μ m fractions were 1.71, 0.85, 0.38, and 0.48 μ g l^{-1}, respectively. The mean relative compositions of the <2, 2-10 and >10 μ m fractions were 50, 22 and 28%, respectively, with the <2 μ m fraction generally predominated. Moreover, compared to previous results from the Alaskan Gyre, the total and size-fractionated chlorophyll *a* concentrations were higher in the Western Subarctic Gyre than in the Alaskan Gyre. The relative composition of the >10 μ m fraction in the Western Subarctic Gyre (28%) was approximately twice that of the Alaskan Gyre (13%).

Key words: size-fractionated chlorophyll *a*, Western Subarctic Gyre, summer

Introduction

In the Alaskan Gyre, chlorophyll *a* concentrations have been shown to be low and nearly constant (ca. 0.4 μ g l^{-1}) throughout the year at Station P (e.g., Parsons and Lalli, 1988; Wong et al., 1995). The phytoplankton community in the gyre in summer is dominated by small sized cells (<2 μ m) (Booth, 1988; Odate, 1996). In the Western Subarctic Gyre and the adjacent region, some measurements of chlorophyll *a* concentrations have been carried out from spring to summer (Anderson and Muson, 1972; Kawarada and Sano, 1972; Odate and Maita, 1988/1989; Odate, 1996; Shiomoto et al., 1998). High chlorophyll *a* concentrations exceeding 5 μ g l^{-1} were observed during blooms from spring to summer in the western subarctic Pacific (Kawarada and Sano, 1972; Odate and Maita, 1988/1989; Shiomoto et al., 1998). The concentrations in the Western Subarctic Gyre, except for spring blooms, have been generally found to approximate 0.5-1 μ g l^{-1} (Shiomoto et al., 1998) and tend to be higher than in the Alaskan Gyre. However, few studies of size composition of phytoplankton have been conducted in the Western Subarctic Gyre. Odate (1996) reported that during summer small sized phytoplankton (<2 μ m) commonly dominate the phytoplankton communities in the western and eastern subarctic Pacific. Further information about size-fractionated chlorophyll *a* concentrations and their relative compositions is necessary for the Western Subarctic Gyre. Here, we present results of size-fractionated chlorophyll *a* concentrations and their relative compositions for the Western Subarctic Gyre in July 1997.

Materials and Methods

This study was conducted during cruises of the R/V *Hokko Maru*, which is owned by the Hokkaido National Fisheries Research Institute and was operated by the National Research Institute of Far Seas Fisheries in July 1997. Stations were located every 1° between 48° N and 51° N along 165° E (Fig.1). Seawater samples were collected at four depths corresponding to 100, 30, 10, and 1% of the solar radiation at the sea surface determined with 2 π quantum sensor (LI-COR Model 1000), using a 30 l Niskin PVC sampler with Teflon-coated steel springs. The samples (0.5-1 l) were filtered separately through Nuclepore filters with pore sizes of 2 and 10 μ m and Whatman GF/F filters. Those filters were immediately frozen at -20° C and preserved for later determination on land. Chlorophyll *a* was extracted with 90% acetone at -20° C for 24 hours in the dark, according to Parsons et al. (1984). Chlorophyll *a* concentration was determined by fluorometry using a Hitachi F-2000 fluorometer.

In this study, we refer to the chlorophyll *a* retained

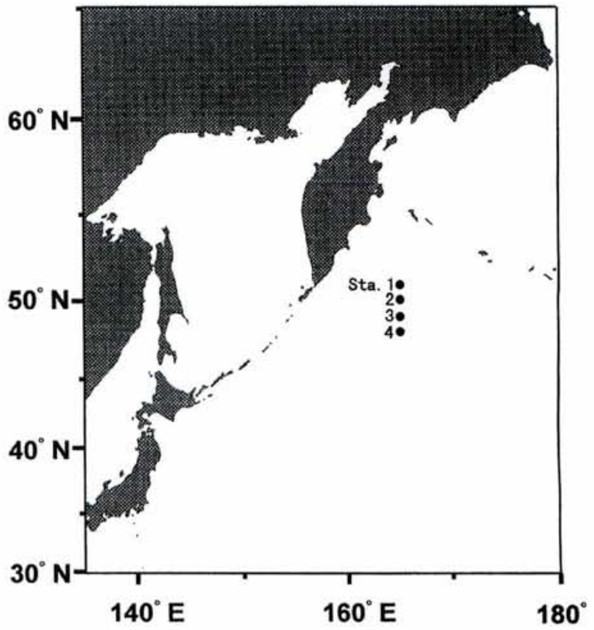

Fig. 1. Location of sampling stations in July 1997.

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on GF/F filters as the total chlorophyll *a*. The size fraction of less than 2 μ m was obtained by subtracting chlorophyll *a* retained on the 2 μ m filter from the total chlorophyll a. The 2-10 μ m fraction was calculated by subtracting the chlorophyll a retained on the 10 μ m filter from that collected on the 2 μ m filter. We refer to the chlorophyll *a* retained on the 10 μ m filter as the size fraction of more than 10 μ m.

The seawater samples for nutrient determination (nitrate+nitrite and silicate) were stored frozen at -20° C. Concentrations were determined with a Bran and Lubbe TRAACS 800. Temperature and salinity were measured with a Neil Brown Mark IIIB CTD system.

Results and Discussion

The Western Subarctic Gyre is situated north of the Transition Domain, the northern boundary of which is bordered by water of more than 4° C below 100 m (Favorite et al., 1976). The Western Subarctic Gyre is characterized by the occurrence in summer of a seawater temperature minimum layer (dichothermal layer, <4° C) below 100 m (Favorite et al., 1976; Nagata et al., 1992). In this study, the dichothermal layer occurred from Station 1 to Station 4 at depths of *ca.* 100 m (Fig. 2). Thus, Stations 1-4 were located in the Western Subarctic Gyre with salinity being almost uniform (32.8-33.0) above *ca.* 100 m and a pycnocline occurred at *ca.* 30 m (Fig. 2). Nitrate+nitrite and silicate concentrations above depths of 1% light were in the range of 15.2-21.6 and 30.9-42.7 μ M, respectively (Table 1). Nitrate+nitrite and silicate concentrations within the euphotic layer averaged 18.4 and 38.1 μ M, respectively.

Concentrations of the total and size-fractionated chlorophyll *a* in the euphotic layer (100, 30, 10, and 1% light depths) are shown in Table 1. The total chlorophyll *a* concentrations ranged from 0.42 to 2.61 $\mu g\ l^{-1}$ and were more than 1.5 $\mu g\ l^{-1}$, except for the values at 1% light depths of Stations 1 and 4. Mean total chlorophyll *a* concentration in the euphotic layer for all stations was 1.71 $\mu g\ l^{-1}$. Chlorophyll *a* concentrations in the <2 μ m fraction ranged from 0.01 to 1.56 $\mu g\ l^{-1}$, the 2-10 μ m fraction from 0.09 to 0.74 $\mu g\ l^{-1}$, and the >10 μ m fraction from 0.13 to 1.34 $\mu g\ l^{-1}$. The mean concentrations of the <2, 2-10 and >10 μ m fraction were 0.85, 0.38, and 0.48 $\mu g\ l^{-1}$, respectively.

Relative compositions of the <2 μ m fraction ranged from 1 to 63% with most values in the range of 40 to 60% and the mean relative composition was 50%. The relative compositions of the 2-10 μ m fraction ranged from 13 to 56 % and the mean relative composition was 22%. The relative compositions of the >10 μ m fraction were from 15 to 77% and the mean relative composition was 28%. Therefore, the <2 μ m fraction generally predominated in this study. Within the euphotic zone, the concentrations of the total and size-fractionated chlorophyll *a* at the 1% light depths tended to be the lowest in the euphotic layer. The relative compositions of size-fractionated chlorophyll *a* did not show any regular trend with depth.

Our results described above were similar to Odate

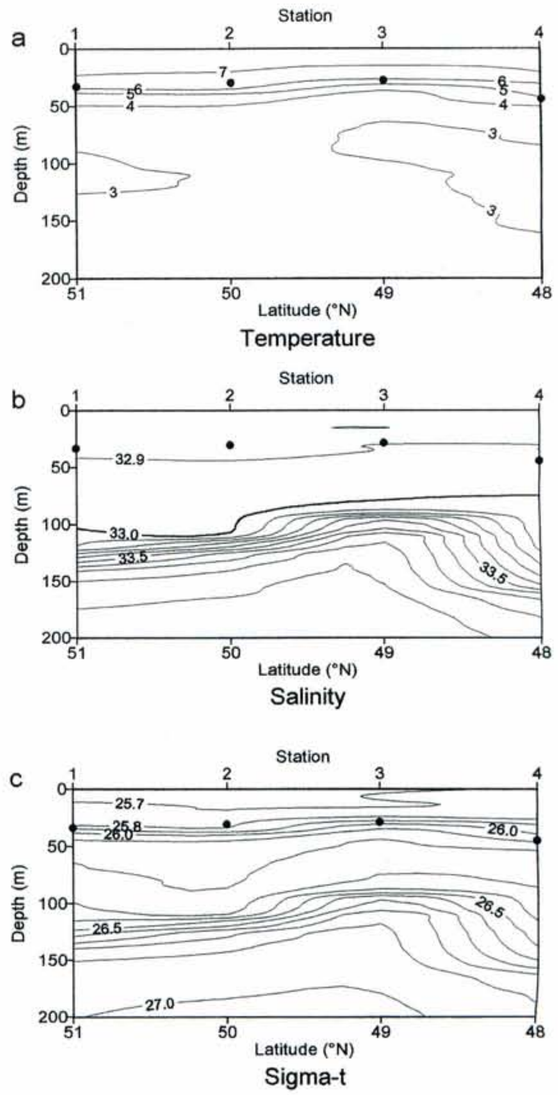

Fig. 2. Spatial variations of temperature (° C), salinity and sigma-t shallower than 200 m between 48° N and 51° N along 165° E in July 1997. Closed circles indicate the 1% light depth.

(1996), who showed that the total chlorophyll *a* concentrations were *ca.* 1 $\mu g\ l^{-1}$ and were dominated by the <2 μ m fraction in the western subarctic Pacific in summer. Consequently, in the western subarctic Pacific during summer, the total chlorophyll *a* concentrations tend to approximate or exceed 1 $\mu g\ l^{-1}$ and seem to be generally dominated by the <2 μ m fraction.

In the Alaskan Gyre, chlorophyll *a* concentrations are ca. 0.4 $g\ l^{-1}$ throughout the year at Station P (e.g., Parsons and Lalli, 1988; Wong et al., 1995). The total and size-fractionated chlorophyll *a* concentrations in summer were clearly higher in the Western Subarctic Gyre than in the Alaskan Gyre with the total chlorophyll *a* concentrations in the Western Subarctic Gyre being about 4 times higher than in the Alaskan Gyre (Table 2). The concentrations of small (<2 or <5 μ m), middle (2-10 or 5-10 μ m) and large (>10 μ m) sized fractions were about 3, 5 and 10 times higher in the Western Subarctic Gyre than in the Alaskan Gyre,

Table 1. Concentrations of size-fractionated chlorophyll *a* and nutrients (nitrate+nitrite, silicate) in the Western Subarctic Gyre. Percentage relative compositions are shown in parentheses.

Station	Light (%)	Depth (m)	Nitrate+Nitrite (μM)	Silicate (μM)	Chlorophyll a(μg l⁻¹) <2 μm	2-10 μm	>10 μm	Total
1	100	0	18.3	38.4	1.05 (46%)	0.51 (22%)	0.74 (32%)	2.30
	30	7	18.3	39.3	0.96 (48%)	0.44 (22%)	0.62 (31%)	2.02
	10	14	18.4	39.8	1.04 (53%)	0.31 (16%)	0.60 (31%)	1.95
	1	33	19.7	37.9	0.24 (38%)	0.13 (20%)	0.27 (42%)	0.64
2	100	0	18.2	38.9	1.35 (55%)	0.60 (24%)	0.51 (21%)	2.46
	30	5	18.3	38.9	1.23 (57%)	0.48 (22%)	0.46 (21%)	2.17
	10	12	18.2	39.3	0.01 (1%)	0.74 (56%)	0.56 (43%)	1.31
	1	30	19.7	39.5	1.42 (64%)	0.32 (14%)	0.48 (22%)	2.22
3	100	0	16.5	33.6	1.46 (58%)	0.50 (20%)	0.54 (22%)	2.50
	30	6	15.2	30.9	1.56 (60%)	0.53 (20%)	0.52 (20%)	2.61
	10	13	16.3	33.7	1.40 (57%)	0.55 (22%)	0.52 (21%)	2.47
	1	28	20.3	39.0	0.17 (10%)	0.23 (13%)	1.34 (77%)	1.74
4	100	0	17.3	37.0	0.90 (55%)	0.35 (21%)	0.40 (24%)	1.65
	30	8	17.6	37.7	1.05 (63%)	0.37 (22%)	0.26 (15%)	1.68
	10	18	17.3	37.4	0.97 (60%)	0.36 (22%)	0.30 (18%)	1.63
	1	44	21.6	42.7	0.20 (48%)	0.09 (21%)	0.13 (31%)	0.42
Mean			18.4	38.1	0.85 (50%)	0.38 (22%)	0.48 (28%)	1.71

respectively. The relative compositions of size-fractionated chlorophyll *a* were predominated by the small sized phytoplankton in both gyres (Table 2). Furthermore, the percentage of large sized phytoplankton (>10 μm) was about 2 fold higher in the Western Subarctic Gyre than in the Alaskan Gyre, that is, this fraction averaged 28% in the Western Subarctic Gyre whereas 13% in the Alaskan Gyre. Odate (1996) showed that the relative composition of the >10 μm fraction was about 10% in the Subarctic Current System of the western North Pacific. Our results of the relative composition of large sized phytoplankton are about 3 times higher than the values reported by Odate (1996). Our results show the first observations such a high relative composition of large sized phytoplankton in the Western Subarctic Gyre. These results are supported by light microscopic observations that the large sized diatoms such as *Nitzchia* spp. were abundant (Shiomoto, unpublished data). Spring phytoplankton blooms, which are predominated by large sized phytoplankton such as diatoms, have been observed in the oceanic regions in the western subarctic Pacific (Odate and Maita, 1988/1989; Kasai et al., 1997). The higher contribution of large sized phytoplankton in the Western Subarctic Gyre than in the Alaskan Gyre seems to maintain not only in spring but also in summer.

Recently, it has been suggested by Boyd et al. (1996) that the low chlorophyll *a* concentration in the Alaskan Gyre is due to iron limitation of large sized phytoplankton and also by microzooplankton grazing on small sized phytoplankton. According to Donaghay et al. (1991), the eolian supply of iron tends to be higher in the western Pacific than in the eastern subarctic Pacific. Strom et al. (1993) reported that the estimated grazing impact of the ciliate community averaged about 20% of the primary production at Station P. Herbivorous ciliate biomass may play an important role for the small sized phytoplankton biomass. Planktonic ciliate abundances in summer tended to be smaller in the Western Subarctic Gyre than in the Alaskan Gyre (Strom et al., 1993). Consequently, it is possibly that the difference in concentrations and relative compositions of size-fractionated chlorophyll *a*

Table 2. Comparison of size-fractionated chlorophyll *a* concentrations between the Western Subarctic Gyre (WSG) and the Alaskan Gyre (AG) in summer. Percentage relative compositions are shown in parentheses.

	WSG		AG
<2 μm	0.85 (50%)	<5 μm	0.28 [e] (70% [a])
2-10 μm	0.38 (22%)	5-10 μm	0.07 [e] (17% [c])
>10 μm	0.48 (28%)	>10 μm	0.05 [e] (13% [b])
Total	1.71	Total	0.40 [d]

[a]: Boyd et al. (1996) reported that phytoplankton was dominated by cells <5 μm which compose >70% of community biomass at Station P in early summer.

[b]: After Welschmeyer et al. (1991), the percentage of the >10 μm fraction was calculated by the authors of this paper.

[c]: The percentage of the 5-10 μm fraction is the value that subtracted 70% and 13% from 100%.

[d]: Wong et al. (1995) showed that total chlorophyll a concentration is almost constant (ca. 0.4 $\mu g\ l^{-1}$) throughout the year at Station P.

[e]: The concentrations were calculated from the total concentration and relative percentages.

between the two gyre systems may be due to differences in iron supply and microzooplankton (ciliate) abundance. Future quantitative studies are required to determine whether the iron limitation-microzooplankton grazing theory can explain for the differences in the concentrations and the relative compositions of size-fractionated chlorophyll a between the two gyre systems.

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1997年7月の西部亜寒帯環流における植物プランクトンのサイズ組成

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摘 要

夏季における西部亜寒帯太平洋に位置する西部亜寒帯環境の有光層において植物プランクトンのサイズ組成を調べるために，1997年7月にサイズ分画した（2μm未満，2-10μm，10μm以上）クロロフィル*a*濃度を調べた．西部亜寒帯環流におけるトータル，2μm未満，2-10μm，10μm以上画分の平均濃度は，それぞれ1.71，0.85，0.38，0.48μg l^{-1}であった．2μm未満，2-10μm，10μm以上画分の相対的な割合の平均値は，それぞれ50，22，28%で，2μm未満の画分が最も大きな割合であった．これらの結果をアラスカ環流において報告されたものと比較すると，トータル，2μm未満，2-10μm，10μm以上画分の濃度は，いずれも西部亜寒帯環流の方が高く，10μm以上画分の相対的な割合（28%）はアラスカ環流（13%）の約2倍の割合であった．

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