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Spring and Summer Phytoplankton Chlorophyll *a* Size Fractions (>10 μm and <10 μm) in the Offshore Waters around Japan

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Abstract Size fractionated phytoplankton chlorophyll *a* (>10 μm and <10 μm) were determined for the waters in the surface mixed layer of the offshore areas around Japan in spring and summer. The chlorophyll *a* concentration of >10 μm fraction largely varied with the sampling locations ranging from almost zero to 5.3 μg ℓ^{-1}. On the other hand, the chlorophyll *a* concentration of <10 μm fraction showed relatively narrow range of variation being roughly lower than 0.5 μg ℓ^{-1}. The obtained results provided the evidence of the ubiquitous occurrence of small-sized phytoplankton in the offshore waters around Japan as reported in other regions, while the abundance of large-sized ones can be affected by the status of the environmental conditions.

Key words: chlorophyll, Japan, phytoplankton, size fraction

INTRODUCTION

Ubiquitous occurrence of small-sized phytoplankton has been recognized in recent studies, for example, prasinophytes of 10^3-10^6 cells mℓ^{-1} by THRONDSEN (1976, 1978), cyanobacteria of 10^4-10^5 cells mℓ^{-1} by WATERBURY *et al.* (1979), and prochlorophytes of *ca.* 10^5 cells mℓ^{-1} by CHISHOLM *et al.* (1988) (*cf.* OLSON *et al.* 1990). FURUYA and MARUMO (1983) also observed the occurrences of small-sized unicellular cyanophytes, haptophytes and cryptophytes in the western North Pacific Ocean, and emphasized their importance in carbon-based biomass as well as in cell number among primary producers in the oceanic area.

There are a variety of protocols to fractionate the phytoplankton assemblage by size depending on the methods and interests of respective planktologists. Although the terms "nano" and "micro"-plankton are widely accepted for the planktonic organisms of 2-20 μm and 20-200 μm, respectively (DUSSART, 1965), different size ranges have been defined for plankton collected with nets (*cf.* TANIGUCHI, 1989; YAMAMOTO, 1989).

In this study, the authors describe the abundances of smaller-sized phytoplankton that are less than 10 μm and larger-sized ones which are bigger than 10 μm in the offshore waters around Japan. The reasons for adopting the size descrimination at 10 μm are; 1) the critical size for routine identification of fixed natural communities under a light microscopy of normal grade is about 10 μm (YAMAMOTO, 1983), and 2) 10 μm is considered to be the critical size to discriminate solitary phytoplankton from chain-forming species as suggested by VAN VALKENBURG and FLEMER (1974).

OBSERVATIONS AND ANALYTICAL METHODS

Seawater samples were collected from six different depths (0, 10, 30, 50, 75 and 100 m) of the various offshore waters around Japan as shown in Fig. 1. The season of the samplings were also varied, and many of them were from spring to summer; May 29, 1978, June 4, 1979, May 9-26, 1980, February 18-March 24, 1981, May 8-15, 1981, July 6-August 4, 1981, April 27-May 26, 1982 (samples were collected by Drs. H. SASAKI and H. HATTORI), June 9–July 8, 1982. The seawater was filtered through gauze of 10 μm mesh, and the filtrate was filtered again with Whatman GF/C glass fiber filter.

Chlorophyll *a* was determined for the precipitates both on the gauze and the filter basically by following the fluorometric method of SAIJO and NISHIZAWA (1969). To extract the pigments, organisms on the gauze were processed by sonication and those on the filter were mechanically homogenized. Since the extraction efficiencies were not significantly different (t-test, P=0.05) between homogenization and sonication of the same sample filtered through GF/C filter (Table 1), no correction was done for the data obtained using 10 μm gauze. However, the extraction efficiency of homogenization was 1.02-fold higher than sonication.

Only the data set obtained in the surface mixed layer were dealt with in this paper.

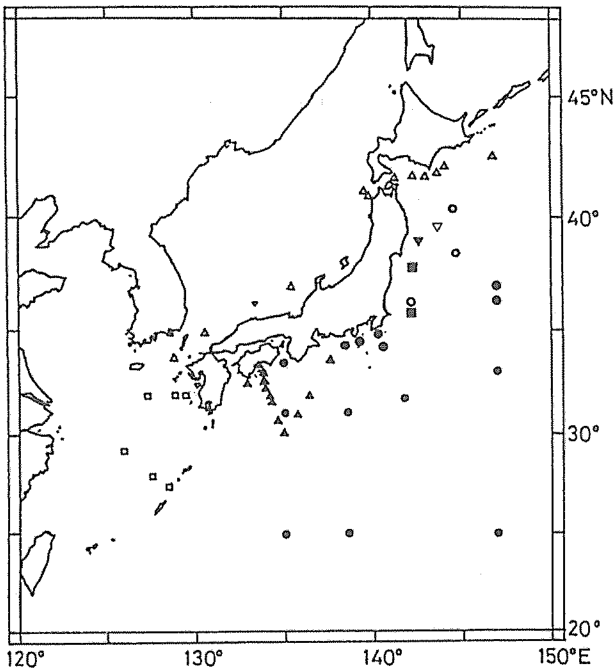

Fig. 1. Locations of the sampling stations. (The sampling period: ▽: May 29, 1978, ▼: June 4, 1979, □: May 9-26, 1980, ●: February 18-March 24, 1981, ■: May 8-15, 1981, ○: July 6-August 4, 1981, △: April 27-May 26, 1982, ▲: June 9-July 8, 1982.)

Table 1. Results of replicate analysis of chlorophyll *a* extraction in 90 % acetone with sonification and homogenization. Extraction efficiencies of both processes were not significantly different (t-test, $p=0.05$), but 1.02-fold higher with homogenization than sonification.

Sample No.	Sonification	Homogenization
1	61.35	58.69
2	59.63	60.97
3	57.28	61.58
4	55.68	58.76
5	57.96	58.86
$\bar{X}$	58.38	59.77
S^2	3.81	1.55

The surface mixed layer mentioned here is not determined by the density gradient of the water column exactly but from the vertical profile of chlorophyll *a*. Although the vertical profiles of chlorophyll are differnt in seasons, chlorophyll abundant layer is generally present in the surface mixed layer and/or in the seasonal pycnocline of the euphotic zone. Then, the data collected at the deeper layer where chlorophyll *a* concentrations were extremely poor were omitted. Since physical and chemical parameters were not observed in some cruises, those are not concerned with in the present paper.

RESULTS AND DISCUSSION

Chlorophyll *a* concentration of $>10\,\mu m$ size fraction largely varied with the location of sampling stations (Fig. 2). The concentration was high in the Oyashio water (0.01-5.3 $\mu g\ \ell^{-1}$), intermediate in the southern coastal water of Japan (0.01-1.4 $\mu g\ \ell^{-1}$)and the Tsugaru warm water and the water of the Japan Sea (0.03-0.27 $\mu g\ \ell^{-1}$), and low in the southern oceanic areas such as the Kuroshio water and the Kuroshio Counter Current water ($<0.1\ \mu g\ \ell^{-1}$). Increasing tendency of the occurrence of larger size fraction towards coastal area from offshore area is well agreed with the reports of MALONE (1971) in the eastern Pacific Ocean and of TUNDISI (1971) in the Atlantic Ocean.

On the other hand, those of $<10\,\mu m$ showed relatively narrow range of variation of roughly lower than 0.5 $\mu g\ \ell^{-1}$(Fig. 2). In neritic waters such as bays and estuaries in Japan, the reported values of total chlorophyll *a* concentration (Iizuka, 1985) far exceed the values observed here. However, the $<10\,\mu m$ chlorophyll *a* concentrations recently measured in Funka Bay (MAITA and ODATE, 1988) did not exceed 0.5 $\mu g\ \ell^{-1}$ as observed in offshore waters in the present study. These results indicate that the $<10\,\mu m$ sized phytoplankton expected to be distributed rather uniformly irrespective of areas and seasons. The same, uniformity of microzooplankton and variability of net-zooplankton in relative sense, is the case among zooplankton community (TANIGUCHI, 1989).

It is demonstrated by MALONE (1980) that there is a clear positive relationship between cell size and half-saturation constant (ks) of nutrient uptake kinetics. Since phytoplankton absorb nutrients through their cell surface and amount of the nutrients required is proportional to their cell volume, small-sized ones are advantageous in the environments of low nutrient concentration because of the larger ratio of cell surface area to cell volume. On the other hand, the large-sized species can be prosperous only in nutrient rich environments

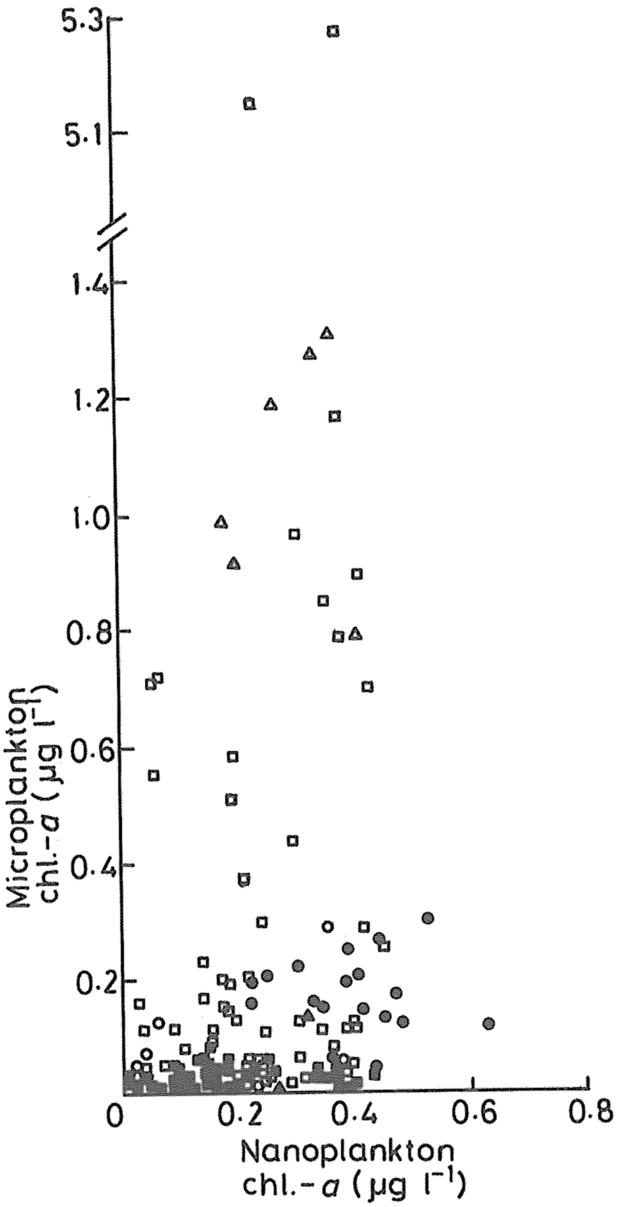

Fig. 2. Relationship between >10 µm and <10 µm chlorophyll *a* size fractions in the offshore waters around Japan in spring and summer. □ : the Oyashio water, △ : the southern coastal water, ○ : the Tsugaru warm water and the water of the Japan Sea, ■ : the Kuroshio water and the Kuroshio Counter Current water, ● : the Kuroshio frontal zone, ▲ : perturbed area between the Oyashio front and the Kuroshio front.

such as coastal areas, upwelling areas and so on. TAKAHASHI and BIENFANG (1983) observed in the water off Hawaii that photosynthetic rate was inversely proportional to phytoplankton cell size.

Because of the nominal porosity of the GF/C filter (*ca.* 1.2 μm), some portion of pico-sized plankton must pass through it. According to VENRICK *et al.* (1987), with the samples collected at subarctic and subtropical stations in the north Pacific Ocean, several percent of total chlorophyll passed through it. Since the investigated area is located closer to the latitude of the above study, it would be considered that the equivalent portion of chlorophyll would be lost. Following the precedent of size definition of planktonic organisms, the <10 μm portion in the present study contains nanoplankton with small part of picoplankton, while the >10 μm portion is a mixture of nano-, micro- and macro-sized phytoplankton.

The observed results provided the ubiquitous occurrence of small-sized phytoplankton (<10 μm portion) in the offshore waters around Japan as reported in other regions. On the other hand, the abundance of large-sized phytoplankton (>10 μm portion) was varied with the location. The increasing trend of the large-sized plankton biomass was recognized in the regions where nutrient concentrations are considered to be high, such as the Oyashio area and the coastal area. It seems that the large-sized phytoplankton are affected by the difference of nutrient status, but that does not the case of small-sized phytoplankton.

Although we could not discuss about the relationship between the phytoplankton biomass and the environmental conditions because of lack of the physical and chemical data, the authors hope that much more data should be generated and that will help in getting better understandings of size structure of phytoplankton communities and food webs in the waters around Japan.

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日本周辺海域における春季および夏季の植物プランクトンクロロフィル *a* のサイズ画分（$>10\,\mu$mと$<10\,\mu$m）

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春季および夏季において，日本周辺海域表層混合層内の植物プランクトンをサイズ分画（$>10\,\mu$mと$<10\,\mu$m）して，それぞれのクロロフィル *a* を測定した．$>10\,\mu$m 画分のクロロフィル *a* 量は測点の違いによって 0-5.3 $\mu g\,\ell^{-1}$ と大きく変動した．一方，$<10\,\mu$m 画分のクロロフィル *a* 量は 0.5 $\mu g\,\ell^{-1}$ 以下と狭い範囲の変動を示した．ここで得られた結果は，大きなサイズの植物プランクトンが生息環境の影響を受けているのが明確であるのに対して，日本周辺海域においても小さなサイズの植物プランクトンが他の海域と同様に普遍的に存在していることを示すものである．