日本の3内湾における表層のプランクトンおよびセストン

誌名	日本プランクトン学会報
ISSN	03878961
著者名	田口,哲 中島,興基
発行元	日本プランクトン学会
巻/号	19巻2号
掲載ページ	p. 20-36
発行年月	1971年12月

Plankton and Seston in the Sea Surface of Three Inlets of Japan* **

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Abstract

Twenty-three surface skin samples collected by a Garrett screen in three coastal bays were studied and compared with subsurface samples simultaneously obtained from 10-50 cm depths. The identified phytoplankton species were grouped into five groups; (1) 15 species only occurring at surface skin, (2) 13 species usually dominating at surface skin, (3) 7 species periodically dominating at surface skin, (4) 30 species usually dominating in subsurface layer, and (5) 21 other species. The species diversity at the surface skin was found to be higher than in the subsurface layer although no consistent difference was found in total cell number and chlorophyll concentration between the two layers. Particulate organic carbon was markedly concentrated at the surface skin, and the maximum concentration factor (skin layer/subsurface layer) was 17.6. The C/N ratio as well as the concentration of phosphate and ammonia in the surface skin was higher than in the subsurface layer. Zooplankters were also found and concentrated at the surface skin particularly at night. It was thought that there was a distinct micro-environment close to the air/water interface, and that the environment was exceedingly rich in particulate carbon and nourishes a peculiar micro-flora and-fauna.

Introduction

It has been well known that the sea surface is covered with a thin organic film. In the open sea, much of the organic material of the surface film may come from dissolved organic matter within the water column which is concentrated by adsorption onto bubbles carried upward, and dispersed at the air-sea interface when the bubble bursts (Baylor *et al.*, 1962). Javis *et al.* (1967) found that the films were composed of the same type of compounds reported by Garrett (1964), namely, fatty esters, fatty acids (of 8 to 12 carbon atoms), fatty alcohols, and both saturated and unsaturated hydrocarbons. Much of this organic matter in the surface skin was denominated as surface-active, slick-foring material. It has even been suggested that the surface-active materials accumulated at the sea surface may be the nutrient supply for certain types of organisms known to populate the surface (Sieburth, 1965; Harvey, 1966). Phosphate, ammonia and nitrite concentrations also appear to be larger at the sea surface (Goering and Menzel, 1965).

Although bacterioneuston is reported by several workers (Sieburth, 1965; Tsyban, 1971), little is known about the phytoplankton, zooplankton, and seston within the surface skin which constitutes the characteristic environment mentioned above.

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* Presented at the Symposium on biology, physics and chemistry of the sea surface skin, Tokyo, April 6, 1971.

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Recently it was found that the particulate organic carbon was concentrated in the surface skin (Williams, 1967). The purpose of this paper is to make a preliminary estimation on the role of phytoplankton, and zooplankton to seston.

Dr. Teruyoshi Kawamura and Dr. Satoshi Nishizawa of Hokkaido University encouraged the authors during the course of this study and critically read the manuscript. The authors wish to express their thanks to Dr. James P. Thomas of University of Washington for reading and criticizing the manuscript. Authors also indebted to the research members of KT-69-17 cruise and the stuff of *Tansei Maru* of Ocean Research Institute, University of Tokyo, for their kind supports in Mutsu Bay. The work in Futami Bay was partially supported by grant from the Ministry of Education, Japan. The work in Oshoro Bay was partially supported by grant from the Japan Society for the Promotion of Science.

Materials and Methods

Surface skin water 150 μ in thickness was collected by using a 16-mesh stainless steel screen (75×50 cm) as devised by Garrett (1965). The screen was dipped vertically, then turned to horizontal position, and hauled above the sea surface in that position. The water adhered to the screen was drained into a polyethylene bottle. Usually 3 to 4 liters of skin water were taken by 60-80 repetitions of this operation. Samples from one or two subsurface layers (*ca.* 0.1 and/or 0.5 m) were simultaneously taken by a small Van Dorn sampler at Futami Bay and Oshoro Bay and by a vacuum suction at Mutsu Bay for comparison with surface skin samples. Samples were collected from Mutsu Bay on 7 to 9 October, 1969, during the research cruise KT-69-17, Futami Bay on 21 to 23 April, 1970, and Oshoro Bay on 9 to 10 May, 23 to 24 May, 6 to 7 June, and 20 to 21 June, 1970. Samples obtained from the surface skin and subsurface layers were divided into two subsamples: one to five percent formalin was added to the fraction used for the identification of phytoplankton and zooplankton under an inverted microscope. The remaining fraction was filtered through a Whatman GF/C filter for the determination of particulate organic carbon and nitrogan, and chlorophyll *a* and pheopigments. The filtrate was used for the determination of reactive phosphorus and ammonia; the filter used for the filtration was a Whatman GF/C at Futami Bay and a millipore filter (HA) at Mutsu Bay and Oshoro Bay.

Particulate organic carbon and nitrogen were analyzed using a 026 Hitachi CHN Analzer. An adsorption correction of filters containing dissolved organic matter was made: 70 μgC/sheet and 10 μgN/sheet for a 47 mm Whatman GF/C filter (Nishizawa *et al.*, unpublished ; *cf.* Ichikawa, unpublished). Chlorophyll *a* and pheopigments were determined by the method of Saijo and Nishizawa (1969) using a fluorometer (Hitachi 139). Reactive phosphorus was analyzed by the method described by Strickland and Parsons (1968). Ammonia was analyzed by the method of Solórzano (1969). The light-photosynthesis experiments were carried out by the method of Taguchi (1970).

Phytoplankton Community

Mutsu Bay (Aomori Prefecture)

Collections were made at the central station of the bay at 1100 on 7 October, 1330 on 8 October and 0900 on 9 October, 1969 both from the surface skin and from a depth of 10 cm.

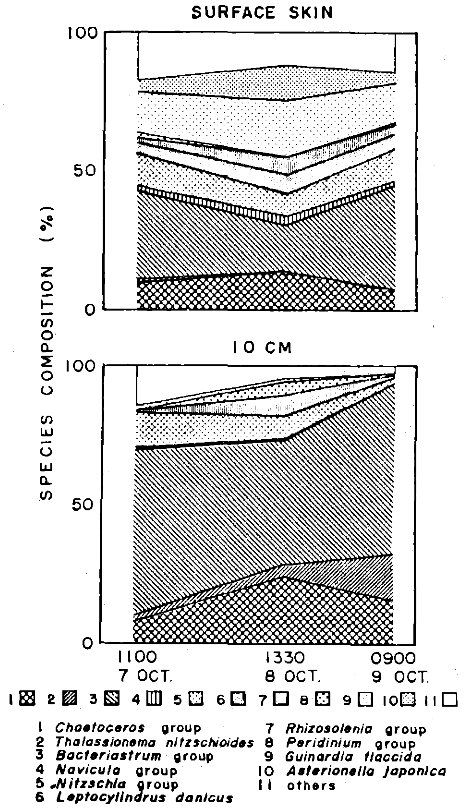


Fig. 1. Short-term variation in the species composition of phytoplankon at a surface skin and a 10-cm depth in Mutsu Bay during the period from 7 to 9 October, 1969 (KT-69-17).

Species composition of phytoplankton from this station is shown in Fig. 1.

Chaetoceros group : This group represented about 10 % of the total phytoplankton cell number in the surface skin and about 20 % in the subsurface layer.

Thalassionema nitzschioides : This species occupied less than 1 % in the surface skin. In the subsurface layer, however, this species occupied from 2 % on 7 October to 16 % on 9 October.

Bacteriastrum group : This group was the first dominant group in the bay. The abundance of this group ranged from 17 % to 37 % in the surface skin and from 45 % to 60 % in the subsurface layer.

Navicula group : This group was three times more abundant in the surface skin than in the subsurface layer.

Leptocylindrus danicus : This species occupied about 5 % in the surface skin and was not found in the subsurface layer.

Rhizosolenia group : This group occupied about 5 % in both layers.

Peridinium group : This group was more abundant in the subsurface layer than in the surface skin. However, it represented only 5 % of the cell number, even in the subsurface layer.

Guinardia flaccida : This species ranged from 15 % to 20 % in the surface skin. However, it represented less than 2 % of the phytoplankton cell numbers in the subsurface layer.

Asterionella japonica : This species ranged from 5 % to 15 % in the surface skin. However, in the subsurface layer this species was not found.

Species diversity in the surface skin was higher than in the subsurface layer.

Futami Bay (Bonin Islands)

Daily collections from the surface skin and the 10 cm depth were made at the central station of the bay at 1400 during the period from 21 to 23 April, 1970. Species composition of phytoplankton from both layers is shown in Fig. 2.

Chaetoceros group : This group decreased from about 23 % on 21 April to 0 % on 23 April in both layers.

Thalassionema nitzschioides : This species occurred only in the surface skin but occupied less than 6 %.

Navicula group : Occurrence of this group in the subsurface layer was higher than in the surface skin. It ranged from 4 % to 9 % in both layers.

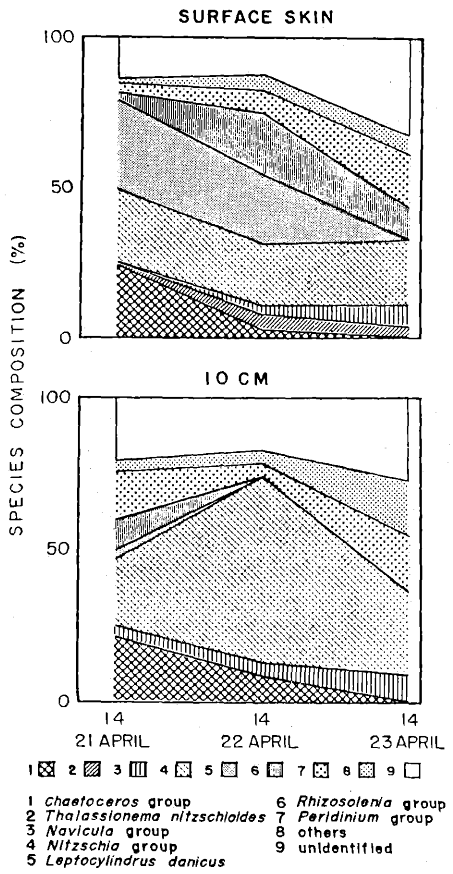


Fig. 2. Short-term variation in the species composition of phytoplankton at a surface skin and a 10-cm depth in Futami Bay during the period from 21 to 23 April, 1970.

Nitzschia group : This group occupied about 20 % in the surface skin. However, in the subsuface layer it varied from about 22 % on April to about 60 % on 22 April, 1970.

Leptocylindrus danicus : Occurrence of this species decreased sharply from about 30 % on 21 April to 0 % on 23 April in the surface skin. In the subsurface layer this species occupied about 3 % on 21 April and was not found on 22 and 23 April.

Rhizosolenia group : This group increased in number from about 3 % on 21 April to about 20 % on 22 and 23 April in the surface skin. However, in the subsurface layer this species was 10 % on 21 April and was not found on 22 and 23 April.

Peridinium group : This group increased in number from 3 % on 21 April to 18 % on 23 April in the surface skin. No such trend was found in the subsurface layer. In the subsurface layer this species occupied 5 % on 22 April and about 16 % on both 21 and 23 April.

Unidentified species in both layers ranged from 13 % to 32 %. Species diversity in the surface skin was higher than in the subsurface layer.

Oshoro Bay (Hokkaido)

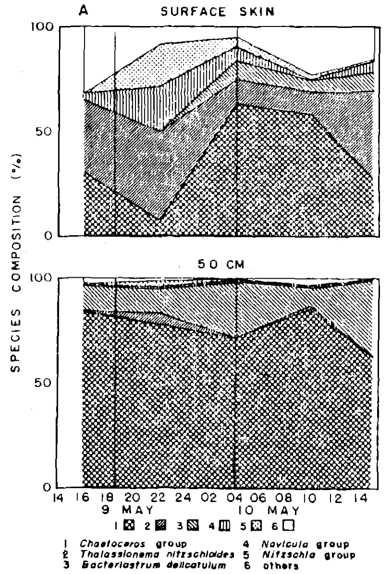
First collections from the surface skin and the 50 cm depth were made at the central station of the bay at 1600 and 2200 on 9 May and 0400, 1000 and 1500 on 10 May, 1970. Species composition of phytoplankton from both layers is shown in Fig. 3-a.

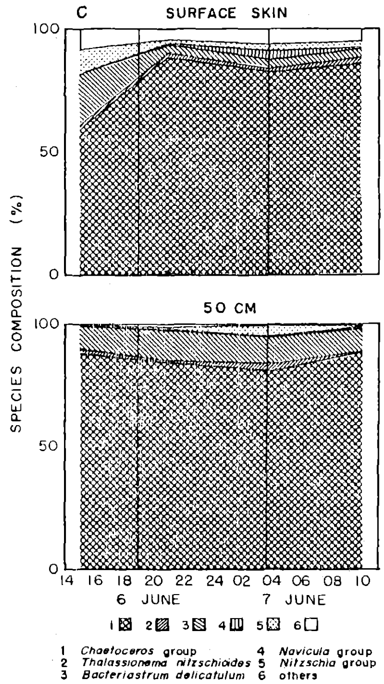
Chaeotceros group : In the surface skin this species increased during the night to a maximum (63 %) at 0400, and decreased during the daytime to a minimum (10 %) at 2100. A similar short-term variation was not found in the subsurface layer.

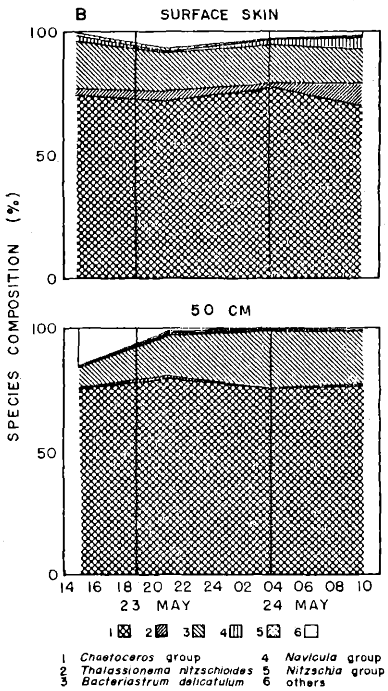
Thalassionema nitzschioides : In the surface skin this species occupied about 40 % in the morning and about 10 % in the afternoon. In the subsurface layer no short-term varition was found for this species.

Bacteriastrum delicatulum : This species was not found in the surface skin at 1600 and 2200 but was found to represent about 10 % of the phytoplankton cell number in this layer at 0400, 1000 and 1500 in the subsurface layer this species ranged from 10 % to 35 %.

Navicula group : This group increased at night a maximum of 20 % at 2100 and decreased at day to a minimum of 1 % at 1000 in the surface skin. In the subsurface layer this species







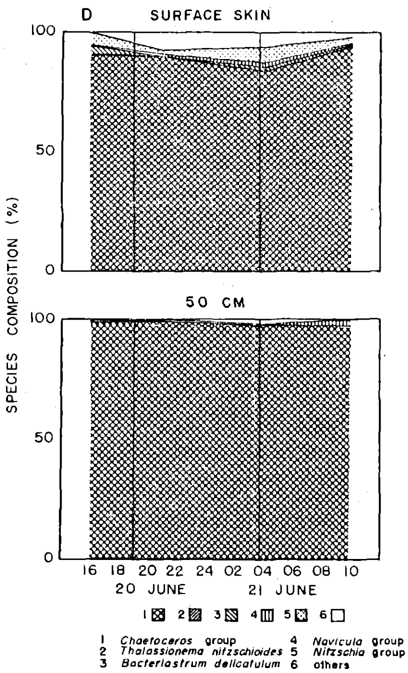


Fig. 3. Short-term variation in the species composition of phytoplankton at a surface skin and a 50-cm depth in Oshoro Bay.
A. the period from 9 to 10 May, 1970.
B. the period from 23 to 24 May, 1970.
C. the period from 6 to 7 June, 1970.
D. the period from 20 to 21 June, 1970.

showed no short-term variation and was less than 2 %.

Nitzschia group : This group increased at night to a maximum of 20 % at 2100 and decreased at day in the surface skin. On the other hand, it showed no short-term variation and was less than 3 % in the subsurface layer.

Species diversity in the surface skin was higher than in the subsurface layer.

Second collections from the surface skin and the 50 cm depth were made at the central station of the bay at 1600 and 2100 on 23 May and at 0400 and 1000 on 24 May, 1970. Species composition of phytoplankton from both layers is shown in Fig. 3-b.

The following five groups ; *Chaetoceros* group, *Thalassionema nitzschioides*, *Bacteriastrum delicatulum*, *Navicula* group, and *Nitzschia* group showed no short-term variation in both layers.

Third collections from the surface skin and the 50 cm depth were made at the central station of the bay at 1600 and 2100 on 6 June and at 0400 and 1000 on 7 June, 1970. Species composition of phytoplankton from both layers is shown in Fig. 3-c.

Species composition in the surface skin was similar to the one in the subsurface layer. *Chaetoceros* group increased to more than 80 % from 70 % on 23 to 24 May. It may be associated with a phytoplankton bloom.

Four collections from the surface skin and the 50 cm depth were made at the central station of the bay at 1600 and 2100 on 20 June and at 0400 and 1000 on 21 June, 1970. Species composition of phytoplankton from both layers is shown in Fig. 3-d. Species composition in the surface skin was similar to the one in the subsurface layer. The *Chaetoceros* group continued to increase to 90 % from 6 to 7 June. It may be also associated with a phytoplankton bloom.

Total Cell Number of Phytoplankton

Mutsu Bay (Fig. 4)

Total cell number of phytoplankton in the surface skin (126×10^6 cells/m^3) was greater than in the subsurface layer (71.8×10^6 cells/m^3) on 7 October when the sea surface

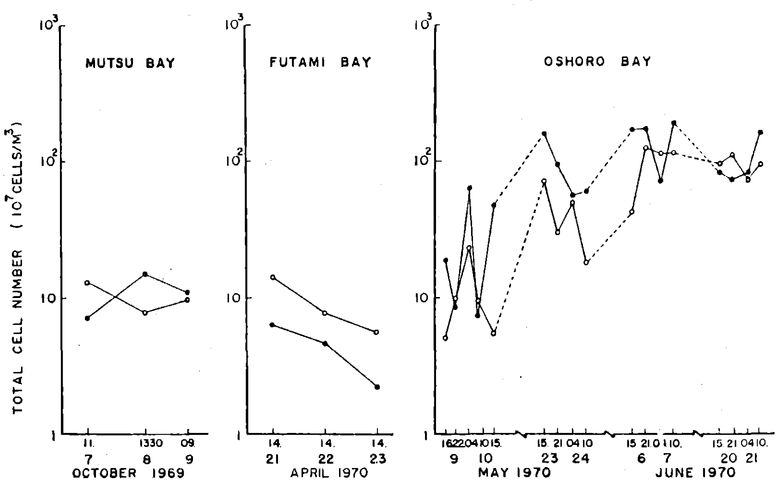


Fig. 4. Total cell number of phytoplankton in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay and Oshoro Bay.

ware calm. However, on 8 and 9 October when the wind was enough to break the sea surface, total cell number in the subsurface layer (151 to 113 × 10^6 cell/m^3) was greater than in the surface skin (79.0 to 98.4 × 10^6 cells/m^3).

Futami Bay (Fig. 4)

As the sea surface was calm during the period from 21 to 23 April, total cell number in the surface skin (14.3 to 5.6 × 10^6 cells/m^3) was greater than the number of cells in the subsurface layer (6.4 to 2.2 × 10^6 cells/m^3).

Oshoro Bay (Fig. 4)

Total cell number in the surface skin was 55.0 to 234 × 10^6 cells/m^3 on 9 to 10 May and 180 to 701 × 10^6 cells/m^3 on 23 to 24 May. Total cell number in the subsurface layer was greater than in the surface skin, being 73.6 to 650 × 10^6 cells/m^3 on 9 to 10 May and 571 to 1630 × 10^6 cells/m^3 on 23 to 24 May. Phytoplankton bloom reached a plateau on 6 to 7 June in both layers ; 428 to 1250 × 10^6 cells/m^3 in the surface skin and 722 to 1940 × 10^6 cells/m^3 in the subsurface layer. Little difference in total cell number was found between both layers on 20 to 21 June ; 721 to 1110 × 10^6 cells/m^3 in the surface skin and 739 to 1630 × 10^6 cells/m^3 in the subsurface layer.

Pigment

Mutsu Bay (Fig. 5)

Amount of chlorophyll *a* in the surface skin decreased from 1.61 mg/m^3 at 1100 on 7 October to 0.80 mg/m^3 at 0900 on 9 October. Amount of chlorophyll *a* in the subsurface layer decreased from 2.40 mg/m^3 at 1100 on 7 October to 0.82 mg/m^3 at 0900 on 9 October. Amount of chlorophyll *a* in the surface skin was less than in the subsurface layer except at 1330 on 8 October.

Futami Bay (Fig. 5)

The lowest range of amount of chlorophyll *a* was found in the bay studied here. Amount of chlorophyll *a* ranged from 0.10 to 0.33 mg/m^3 in the surface skin and from 0.14 to 0.42 mg/m^3 in the subsurface layer. Amount of chlorophyll *a* in the surface skin was less than in the subsurface except on 22 April.

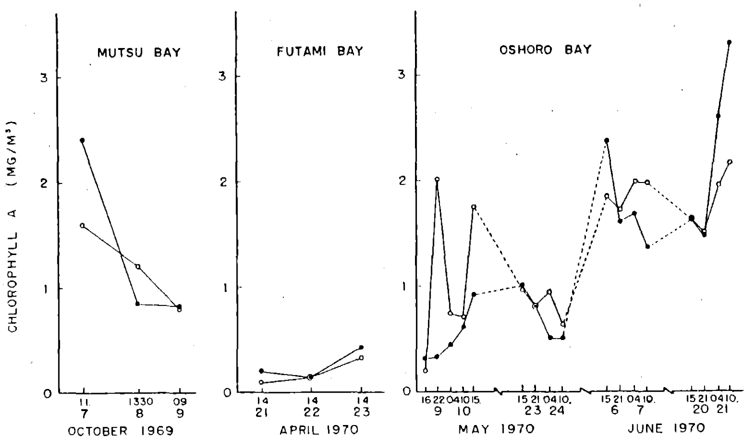


Fig. 5. Chlorophyll *a* in the surface skin (○) and the subsurface (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

Oshoro Bay (Fig. 5)

Amount of chlorophyll *a* in the surface skin was much greater than in the subsurface layer except at 1600 ; maximum was 6.4 times the subsurface value on 9 to 10 May at the start of a phytoplankton bloom. During the course of the bloom the amount of chlorophyll *a* increased in both layers and the difference between the layers remained small. The amount of chlorophyll *a* in the surface skin was less than in the subsurface layer on 20 to 21 June.

Chlorophyll *a* Content of Phytoplankton Cell

Mutsu Bay (Fig. 6)

The chlorophyll *a* content of phytoplankton cells in the suface skin was greater than in the subsurface layer with one exception on 7 October; maximum was 2.7 times that in the subsurface layer on 8 October.

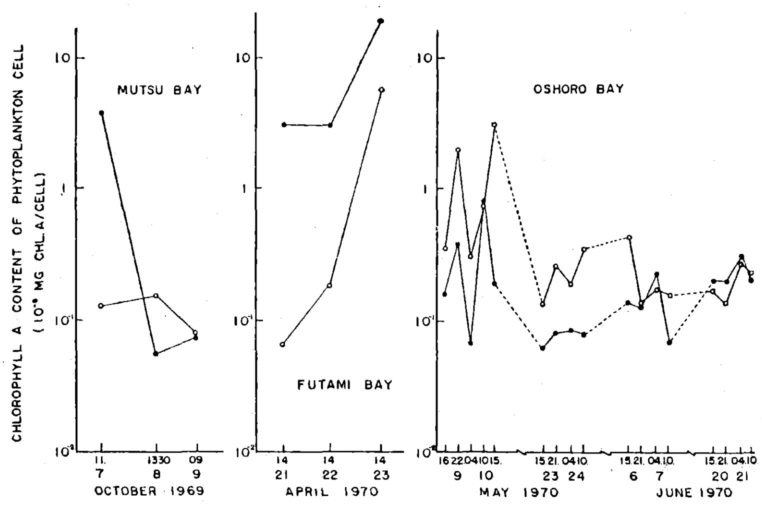


Fig. 6. Chlorophyll *a* content of phytoplankton cells in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

Futami Bay (Fig. 6)

The chlorophyll *a* content of phytoplankton cells in the surface skin was less than in the subsurface layer, and ranged from 0.21 to 0.59 times the subsurface layer values.

Oshoro Bay (Fig. 6)

The chlorophyll *a* content in 9 to 10 May was high, and showed a marked short-term variation both in the surface skin and in the subsurface layer ; the ratio of the maximum over the minimum was more than 10. The chlorophyll *a* content in the skin was 2.2 to 16.7 times greater than in the subsuface layer except for the sample taken at 1000 on 10 May.

In 23 to 24 May and 6 June the chlorophyll *a* content in the skin was 2.1 to 4.3 times greater than in the subsurface layer although the average levels of chlorophyll content in both layers much reduced with the time course of the declining bloom.

In 6 to 7 and 20 to 21 June, the chlorophyll content in both layers converged to a nearly stable common value of about 0.20×10^{-7} mg chl. *a*/cell.

Photosynthesis

Three light-photosynthesis experiments using the ^{14}C technique were carried out on water samples taken from the surface skin and the subsurface layer at the central station of Futami Bay (Fig. 7). The saturated-photosynthetic rate in the surface skin was lower than the rate in the subsurface layer except on 21 April. Low photosynthetic rates in the surface skin might suggest the activity of chlorophyll *a* in the surface skin was depressed by the strong solar radiation.

Particulate Organic Carbon

Mutsu Bay (Fig. 8)

Particulate organic carbon ranged from 235 to 334 mgC/m³ in the surface skin and from 186 to 214 mgC/m³ in the subsurface layer. The concentration factor for the skin layer relative to the subsurface layer ranged from 1.1 to 1.8.

Futami Bay (Fig. 8)

Particulate organic carbon ranged from 185 to 479 mgC/m³ in the surface skin and from 108 to 157 mgC/m³ in the subsurface layer. The concentration factor ranged from 1.2 to 4.4.

Oshoro Bay (Fig. 8)

Maximum concentration of particulate organic carbon in the surface skin was 5174 mgC/m³ at 2200 on 9 May, and with the time course of the bloom particulate organic carbon decreased to a minimum (368 mgC/m³) at 1000 on 21 June. The amplitude of the short-term variations also decreased during the bloom. However, the seasonal variation of the particulate organic carbon in the subsurface layer was very small with the concentration ranging from 124 to 348 mgC/m³. The concentration factor ranged from 1.6 to 17.6.

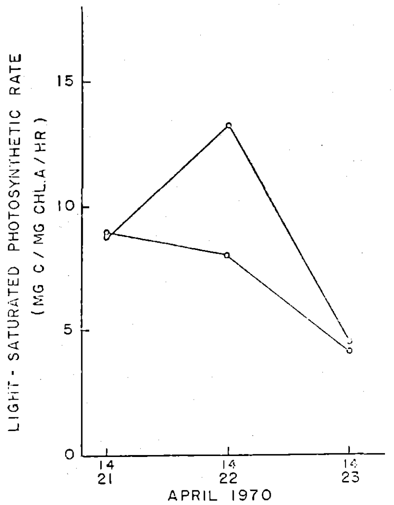


Fig. 7. Light-saturated photosynthetic rate in the surface skin (○) and the 10 cm depth (●) in Futami Bay on 21, 22, and 23, April 1970.

Carbon/Nitrogen Ratio

Mutsu Bay (Fig. 9)

No consistent difference in C/N ratio was found between the surface skin and the subsurface layer except on 7 October when the sea surface was calm. The C/N ratio was more than 5 in the surface skin.

Futami Bay (Fig. 9)

The sea surface was very calm. Again the difference in C/N ratio was very little

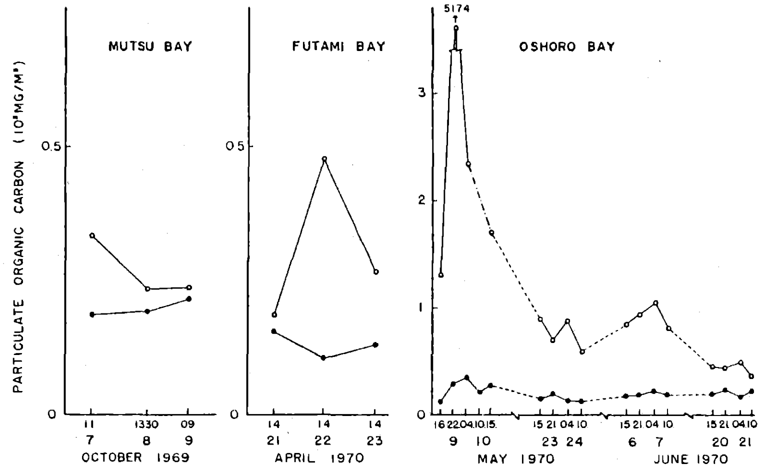


Fig. 8. Particulate organic carbon in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

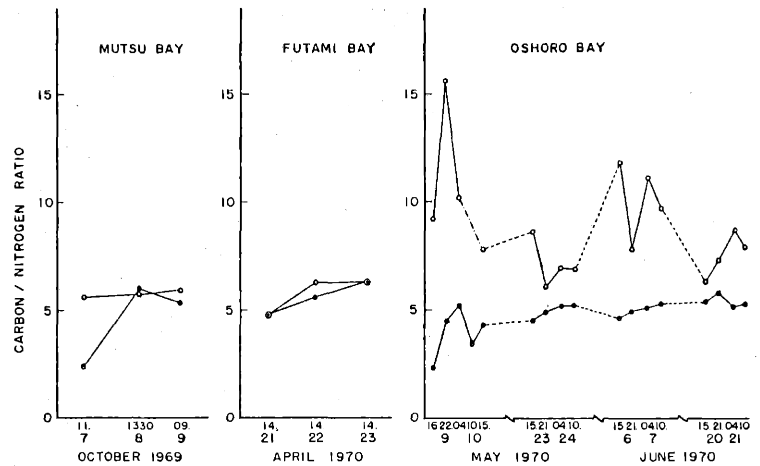


Fig. 9. Carbon/nitrogen ratio in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

between the surface skin and the subsurface layer. The C/N ratio in both layers was in a range from 4.8 to 6.3.

Oshoro Bay (Fig. 9)

The maximum C/N ratio was 15.6 and occurred in the surface skin at 2200 on 9 May at the same time with the particulate organic carbon maximum (5174 mgC/m³). The amplitude of the short-term variation in the ratio during the period from 9 to 10 may was more than 5. The fluctuation decreased during the course of the bloom, and tended to stabilize at the average ratio of 7 to 8. The maximum amplitude of the short-term variation in the subsurface layer was only 3 that occurred in the first sampling period, and the C/N ratio was in a narrow range of 4 to 6 thereafter.

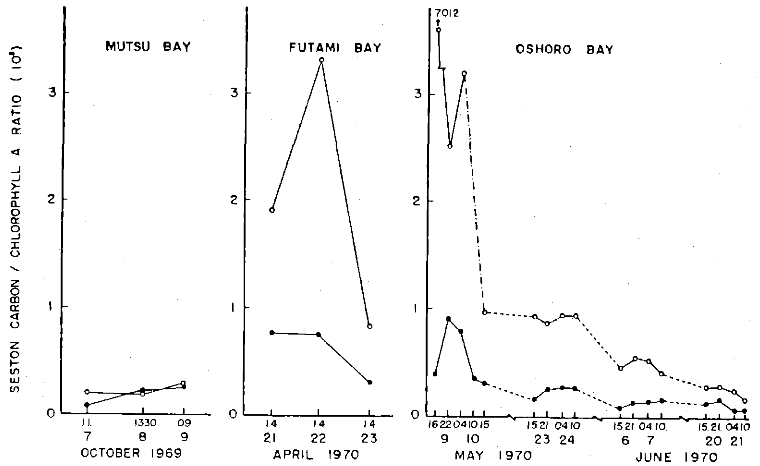


Fig. 10. Seston carbon/chlorophyll *a* ratio in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

Seston Carbon/Chlorophyll *a* Ratio

Mutsu Bay (Fig. 10)

Seston carbon/chlorophyll *a* ratio between the surface skin and the subsurface layer did not differ significantly and ranged from 78 to 296.

Futami Bay (Fig. 10)

Seston carbon/chlorophyll *a* ratio in the surface skin showed a large short-term variation and ranged from 824 to 3320. However, the ratio in the subsurface layer was much less than in the surface skin, ranging from 310 to 777.

Oshoro Bay (Fig. 10)

Seston carbon/chlorophyll *a* ratio in the surface skin showed a large short-term variation and ranged from 974 to 7012 during the period from 9 to 10 May. The ratio gradually decreased to 170 at 1000 on 21 June. All the ratios obtained in the surface skin was higher than in the subsurface layer. The ratio in the subsurface layer ranged from 70 to 910.

Phosphate

Mutsu Bay (Fig. 11)

The phosphate concentration in the surface skin increased from 0.17 μg-at P/*l* on 7 October to 0.63 μg-at P/*l* on 9 October. However, in the subsurface layer the concentration ranged from 0.08 to 0.16 μg-at P/*l*.

Futami Bay (Fig. 11)

The phosphate concentration ranged from 0.11 to 0.15 μg-at P/*l* in the surface skin and from 0.03 to 0.08 μg-at P/*l* in the subsurface layer. The concentration in the surface skin was higher than in the subsurface layer.

Oshoro Bay (Fig. 11)

The phosphate concentration in both the surface skin and the subsurface layer decreased systematically. The concentration ranged from 1.47 μg-at P/l at 2200 on 9 May to 0.05 μg-at P/l at 1000 on 21 June in the surface skin and from 0.49 μg-at P/l at 1600 on 9 May to 0.02 μg-at P/l at 0400 on 7 June in the subsurface layer. The concentration factor also decreased from 5.8 at 2200 on 9 May to 0.8 at 0400 on 21 June.

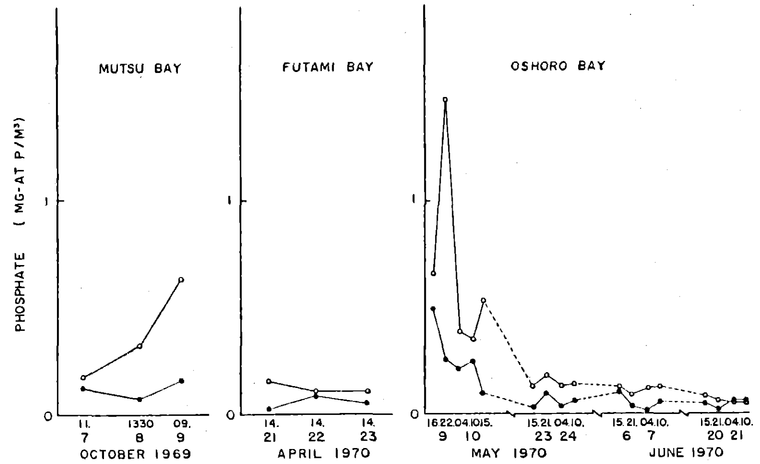


Fig. 11. Phosphate in the surface skin (○) and the subsurface (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

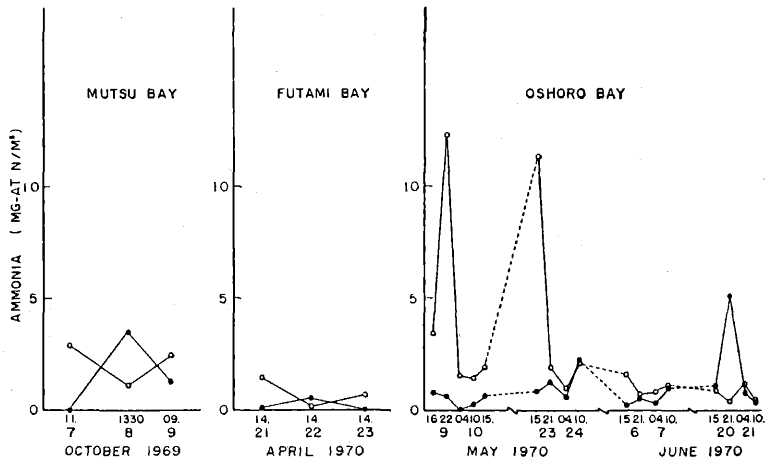


Fig. 12. Ammonia in the surface skin (○) and the subsurface layer (●) in Mutsu Bay, Futami Bay, and Oshoro Bay.

Ammonia

Mutsu Bay (Fig. 12)

The ammonia concentration ranged from 1.11 to 2.87 μg-at N/l in the surface skin and from 0.00 to 3.50 μg-at N/l in the subsurface layer. The concentrations in the surface skin were higher than in the subsurface layer except at 1330 on 8 October.

Futami Bay (Fig. 12)

Ammonia concentrations ranged from 0.19 to 1.49 μg-at N/l in the surface skin and from 0.00 to 0.53 μg-at N/l in the subsurface layer. The concentrations in the surface skin were higher than in the subsurface layer except on 22 April.

Oshoro Bay (Fig. 12)

The ammonia concentration in the surface skin decreased from 12.3 μg-at N/l at 2200 on 9 May to 0.49 μg-at N/l at 2100 on 20 June. However, the concentration in the subsurface layer increased from 0.08 μg-at N/l at 0400 on 10 May to 5.12 μg-at N/l at 2100 on 20 June. The concentration factor also decreased from 18.3 at 2200 on 9 May to 1.2 at 1000 on 20 June.

Zooplankton

Zooplankton was found only for the samples taken in Oshoro Bay. Twelve species were identified as shown in Table 1. A significant difference in zooplankton distribution

Table 1. Numbers of zooplankter collected from surface skin and 50 cm depth in Oshoro Bay during the period from May 9 to June 21, 1970. All numbers in 10^6 individuals per cubic meters.

Species	Depth	MAY 1970					MAY 1970				JUNE 1970				JUNE 1970			
		9		10			23		24		6		7		20		21	
		16	22	04	10	15	15	21	04	10	15	21	04	10	15	21	04	10
Tintinnopsis urnula	SS			0.2														
	50																	
Tintinnopsis ampla	SS							0.6										
	50																	
Tintinnopsis tubulosa	SS								0.6									
	50								0.2									
Tintinnopsis sufflata	SS											0.2						
	50																	
Tintinnopsis spp.	SS																	2.0
	50			0.3												0.6		
Favella campanula	SS											0.2						
	50																	
Parafavella faceta	SS								0.2									
	50																	
Ptychocylis obtusa	SS							0.6	0.4									
	50		0.2					0.2										
Acanthostomella norvegica	SS							6.0	2.2									
	50								0.4	0.2								
Protorhabdonella curta	SS																	
	50							0.4										
Undella columbiana	SS			0.6														
	50		0.6															
Copepod	SS							0.4										
	50											0.2						

between the surface skin and the subsurface layer was found. Zooplankton identified were found mostly from night samples, and usually concentrated in the surface skin. Species diversity of zooplankton was large on 23 ond 24 May, 1970. The occurrence of these species at the surface skin might be attributed to the vertical migration of these species. These species have been commonly found in spring and summer (Motoda, 1971).

Discussion

Most of the identified cells from both skin samples and subsurface samples were diatoms. Unidentified phytoplankton cells were usually very low in occurrence for the Mutsu Bay and Oshoro Bay samples except for the samples taken on 9 and 10 May in which 0.3 to 22.4 % of the total were unidentified. For the Futami Bay samples 23 to 32 % of the total cell numbers in the surface skin and 17 to 27 % of the total in the subsurface layer were unidentified. Most of these were fragmented diatom cells and involved only a few cells of dinoflagellates although naked flagellates, if present, would have dissolved during storage in formalin solution. Although there is a possibility that small flagellates preferentially inhabit the surface skin as reported by Harvey (1966), as far as the present observations are concerned, diatom populations are considered to be dominant over dinoflagellates in the surface skin samples.

Although no drastic change in species composition was found between the skin samples and the subsurface samples, there were a few consistent trends that seem to characterize the skin layer. The species composition in the skin was generally more diversified than in the subsurface layer in all of the observations. The dominant species in the subsurface layer were, too, mostly dominant in the skin, but no single species or group exceedingly predominant over others was found in the skin except for Oshoro Bay. In Oshoro Bay, the *Nitzschia* group was highly dominant in the subsurface layer with a secondary dominant population of *Bacteriastrum delicatulum* throughout the bloom in May and June. The *Nitzschia* group was also dominant in the skin, but with less dominancy. Probably some of the subsurface cells were inevitably collected by the screen sampler, and this caused an overestimation of the *Nitzschia* group in the skin.

The authors tentatively classified all the identified species into five groups according to the occurrence in the skin samples and the subsurface samples (*ca.* 10 cm or 50 cm) (Table 2) ;

(1)	species occuring only at the surface skin	15
(2)	species usually dominating at the surface skin	13
(3)	species periodically dominating at the surface skin	7
(4)	species usually dominating in the subsurface layer	30
(5)	other species	21.

Phytoplankters grouped in (1) were always found in very numbers. Genus *Rhizosolenia* was most representative of group (2). Genus *Chaetoceros* was most representative of groups (4) and (5). According to the determinations of sinking velocities of various cultured and natural phytoplankton ceils (Smayda, 1970) the sinking velocities of phytoplankters grouped in (1) and (2) ranged from 0.11 to 2.23 m/day, and those of phytoplankters grouped in (3), (4), and (5) ranged from 0.30 to 6.0 m/day. It is suggested the difference in buoyancy

Table 2. Ecological separation of phytoplankton.

(1) Species occurred only at surface skin;

Amphora hyalina
Mestogloria minuta
Melosira moniliformis
Licmophora kofordii
Rhabdonema adriaticum
Navicula salinarum
Streptotheca indica
Pseudoeunotia doliolus
Fragilaria striatula
Pleurosigma fasciola
Hemiaulus cuneiformis
Chaetoceros affinis v. *circinalis*
Dinophysis ovum
Ceratium kofordii
Silicoflagellata

(2) Species usually dominated at surface skin;

Rhizosolenia fragilissima
Rhizosolenia stolterfothii
Rhizosolenia alata
Rhizosolenia setigera
Rhizosolenia imbricata
Leptocylindrus danicus
Navicula distans
Rhoicosphenia curvata
Guinardia flaccida
Asterionella japonica
Grammatophora marine
Melosira nummuloides
Pleurosigma intermedium

(3) Species periodically dominated at surface skin;

Thalassionema nitzschioides
Licmophora paradoxa
Lauderia borealis
Pleurosigma normanii
Nitzschia longissima
Chaetoceros radicans
Peridinium spp.

(4) Species usually dominated at subsurface layer;

Nitzschia seriata
Nitzschia delicatissima
Skeletolnema costatum
Fragilaria islandica
Fragilaria cylindrus
Eucampia zoodiacus
Dactyliosolen mediterraneus
Navicula cancellata
Thalassiothrix frauenfeldii
Diploneis weissflogii
Hemiaulus hauckii
Hemiaulus sinensis
Bacteriastrum varians
Bacteriastrum comosum
Bacteriastrum delicatulum
Thalassiosira rotula
Chaetoceros laciniosus
Chaetoceros nipponica
Chaetoceros frichei
Chaetoceros vanheurcki
Chaetoceros denticulatus
Chaetoceros holsaticus
Chaetoceros didymus
Chaetoceros seychellarum
Chaetoceros brevis
Chaetoceros socialis
Chaetoceros curvisetus
Chaetoceros lorenzianus
Chaetoceros compressus
Ceratium fusus

(5) Other species;

Nitzschia closterium
Leptocylindrus minimus
Rhizosolenia calcar avis
Rhizosolenia styliformis v. *longispina*
Hemiaulus membranaceus
Gyrosigma fascicola
Chaetoceros danicus
Chaetoceros dadayi
Chaetoceros lauderi
Chaetoceros rostratus
Chaetoceros debilis
Chaetoceros decipiens
Chaetoceros simplex
Chaetoceros diversus
Chaetoceros distans
Chaetoceros costatus
Chaetoceros atlanticus v. *neapolitana*
Chaetoceros gracilis
Chaetoceros concavicornis
Cocconeis scutellum
Distephanus speculum

could be attributed to the zonation of phytoplankters.

The total cell number as well as chlorophyll *a* concentration was not necessarily large in the surface skin samples. Only particulate carbon was significantly more concentrated in all of the skin samples; the general range of the concentration factor was 1.1 to 17.6 for carbon, and the highest factor was obtained in the early stage of the blooming in Oshoro Bay. The concentration factor for particulate nitrogen was in a range of 1.1 to 5.1, and much lower than for carbon. Thus, carbon/nitrogen ratio in the skin sample was consistently higher and was in a general range of 4.9 to 16 in contrast to the range of 2 to 6.3 in the subsurface layers.

However, there is a severe difficulty in explaining all of these differences in species composition and material concentrations between the skin samples and the subsurface samples. A screening of the sea surface through the use of the stainless screen sampler collects 45 to 55 ml of sea water, and the collected water sample would certainly contain 75 to 100 % of the entire surface film, if present, of the sampled sea surface area (Garrett, 1965). The difficulty is that we do not know how thick the "film" is. If it is assumed that the film is of mono or multimolecular dimension, the thickness would be exceedingly thin, probably less than 300 Å, at most (Garrett, 1965). The volume contribution from the film would be less than 0.02 % of the 50 ml sampled. Thus, we have to consider that more than 99.9 % of the total volume of the "skin sample" was collected from the layers outside the film. Furthermore it is almost impossible to identify from which near-surface microlayers was this volume of water collected; the screen was usually hauled up from 10–30 cm beneath the sea scrface. Under these assumptions, it is not surprising that no significant differences were found in chlorophyll concentration and cell count between the skin samples and the subsurface samples that from 10 to 50 cm depths.

The fairly consistent differences in particulate carbon concentration, however, seems to warrant further elaborate studies. These differences strongly suggest that there is no doubt a distinct micro-environment close to the air/water interface and the environment is exceedingly rich in particulate carbon and nourishes a peculiar micro-flora and fauna.

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