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Phytoplankton biomass and photosynthesis in relation to the environmental conditions in Tokyo Bay[1]

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Phytoplankton biomass and photosynthesis were investigated in relation to physico-chemical environmental conditions in Tokyo Bay from May 1979 through March 1981. Vertical and seasonal variations of chlorophyll *a*, photosynthetic and respiratory activity, and environmental conditions were investigated mainly at Stns. A and T-4 in the inner part of the bay. Seasonal measurements were carried out from the inner part of the bay to Uraga Strait. At Stn. A, phytoplankton cell number varied from 5.3×10^3 to 8.2×10^4/m*l*; high in May, August and February but low in June and July. *Skeletonema costatum* and *Prorocentrum* spp. dominated during most of the period. Surface chlorophyll *a* ranged from 2.7 to 175 mg/m^3 with the maximum in September 1980 and lower values in October to January. Light-saturated gross photosynthesis showed a maximum of 2.98 mgO_2/*l*/hr in September 1980 and a minimum of 0.08 mgO_2/*l*/hr in January 1981 in surface samples. It was high in surface samples and low in deeper samples. On a chlorophyll *a* basis, light-saturated gross photosynthesis of surface samples was low during winter and high during summer in the range of 9.5–80 mgO_2/mgChl.*a*/hr. Although chlorophyll *a* concentration and photosynthetic rates were low during the low temperature period and high during the high temperature period, their relationships to temperature were not clear. Chlorophyll *a* concentrations were generally high when salinity was low, but no definite relationship was observed between photosynthesis and salinity. No clear relationship was observed between chlorophyll *a* and nutrient concentrations.

Key Index Words: *biomass*; *chlorophyll* a; *environmental conditons*; *nutrients*; *photosynthesis*; *phytoplankton*; *respiration*; *Secchi disc depth*; *Tokyo Bay.*

Since the initial work of HOGETSU *et al.* (1959) in the estuarine region off Haneda, many studies about phytoplankton productivity in Tokyo Bay have been published in the two decades. Observations on the seasonal changes of photosynthesis rate and biomass were made by ICHIMURA and KOBAYASHI (1964) and ICHIMURA and ARUGA (1964). ICHIMURA (1967) observed the horizontal distributions of primary production in relation to environmental gradients in the bay. MARUMO and MURANO (1973), MARUMO *et al.* (1974) and MARUMO (1975) studied succession of diatoms and FUNAKOSHI *et al.* (1974), TSUJI *et al.* (1974), YAMAGUCHI and ICHIMURA (1976), ARUGA and SHIBATA (1978) and SHIBATA and ARUGA (1982) studied red tide formation and primary production in the bay. Recently, YAMAGUCHI and SHIBATA (1979) published a review of the primary productivity studies after 1970 by different

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authors with the purpose of understanding the present status of the phytoplankton production in Tokyo Bay. They pointed out that owing to the eutrophication throughout the whole bay as the consequence of great amounts of organic and inorganic substances carried into the bay with urban and industrial effluents from the surrounding areas, the seasonal variation of phytoplankton production has gradually been more difficult to be distinguished.

Although there are some papers dealing with the physiological responses of phytoplankton photosynthesis to salinity (NAKANISHI and MONSI 1965), nutrients (NAKANISHI and MONSI 1965, ICHIMURA 1967, FUNAKOSHI *et al.* 1974), light (ICHIMURA and ARUGA 1964, ICHIMURA 1967, SHIBATA and ARUGA 1982) and temperature (SHIBATA and ARUGA 1982), clear relationships between primary productivity and such environmental factors in Tokyo Bay still remain to be understood.

The objective of the present work is to measure the phytoplankton biomass and photosynthesis at fixed stations in Tokyo Bay and to clarify their relationships to environmental factors for characterizing the coastal phytoplankton.

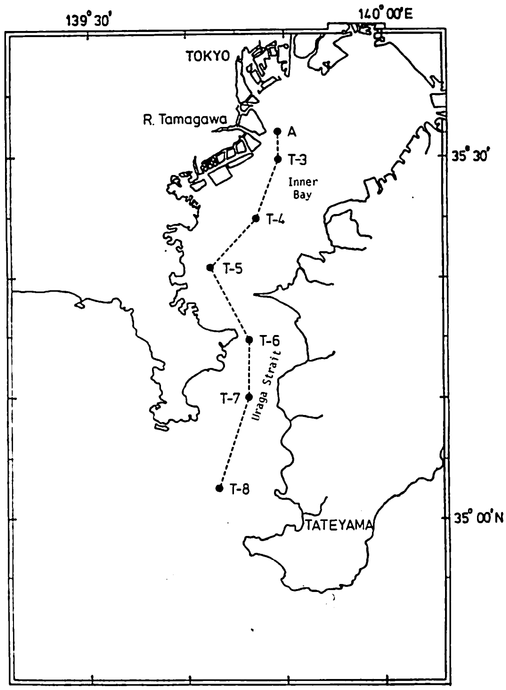


Fig. 1. Map of Tokyo Bay showing the location of stations and the cruise track.

Material and Methods

A total of 19 cruises were made in Tokyo Bay and Uraga Strait from May 1979 through March 1981 by the T/S Seiyo Maru of the Tokyo University of Fisheries. Seven fixed stations were set up as shown in Fig. 1. Vertical water samples were obtained from various depth at Stn. A on the estuarine region off Haneda and at Stn. T-4 with plastic Van Dorn type bottles, and surface water samples were taken with a plastic bucket at 10 or 15 min. intervals from the inner part of Tokyo Bay through Uraga Strait along the cruise track to the entrance of Tateyama Bay for monthly measurements of photosynthesis, respiration, chlorophyll *a*, salinity, temperature and nutrient concentrations.

Annual changes of solar radiation were obtained from the JAPAN METEOROLOGICAL AGENCY (1979-1981). Transparency of water was estimated by the Secchi disc. Temperature was measured with a standard type thermometer and salinity with an Autolab Portable T-S Meter on board the ship for water samples collected. For chlorophyll *a* determinations, the water samples were filtered through Whatman GF/C glass fiber filters and the pigments were extracted with 90% acetone. Extinction values of the extract were read at wavelengths of 750, 663, 645 and 630 nm with a Hitachi 101 or 100 spectrophotometer and chlorophyll concentrations were calculated by the equations of SCOR-UNESCO W.G. 17 (1966). Filtrate samples of about 500 m*l* each were placed into polyethylene bottles and kept frozen for later analyses of nutrients. Silicate, phosphate, nitrate and nitrite were determined following the techniques described by STRICKLAND and PARSONS (1972). Ammonium was estimated according to LIDDICOAT *et al.* (1975) with some modifications concerning the light condition for color development; samples were exposed to fluorescent light (Toshiba FL 20S, W-DL-X/NL) of approximately 5 klux for 6 hr at room temperature.

Photosynthesis and respiration rates were measured by the light and dark bottle oxygen method. Transparent and dark bottles were filled with water samples of approximately 100 m*l* and placed in a fluorescent light incubator at about 25 klux or under natural sunlight on the ship deck at *in situ* water temperature. Photosynthesis-light curves of surface samples from Stn. A were obtained whenever possible using neutral filters consisting of transparent plastic tubes rolled up with vinyl chloride sheets to give different percentages of light. Initial and final oxygen concentrations were determined always in duplicate by means of the Winkler titrations.

Phytoplankton species composition was examined under a microscope in the laboratory after 1 *l* samples were fixed with 8-10 m*l* of glyceraldehyde.

Results and Discussions

1. *Physical and Chemical Properties*

Vertical profiles of temperature, salinity and transparency observed at Stns. A and T-4 are shown in Fig. 2. Surface temperature ranged from 8.1 to 26.3°C at Stn. A and from 8.8 to 24.9°C at Stn. T-4, with the highest value in August and the lowest in February (cf. Fig. 10(A)). Only very slight differences were found of surface temperature and its seasonal changes be-

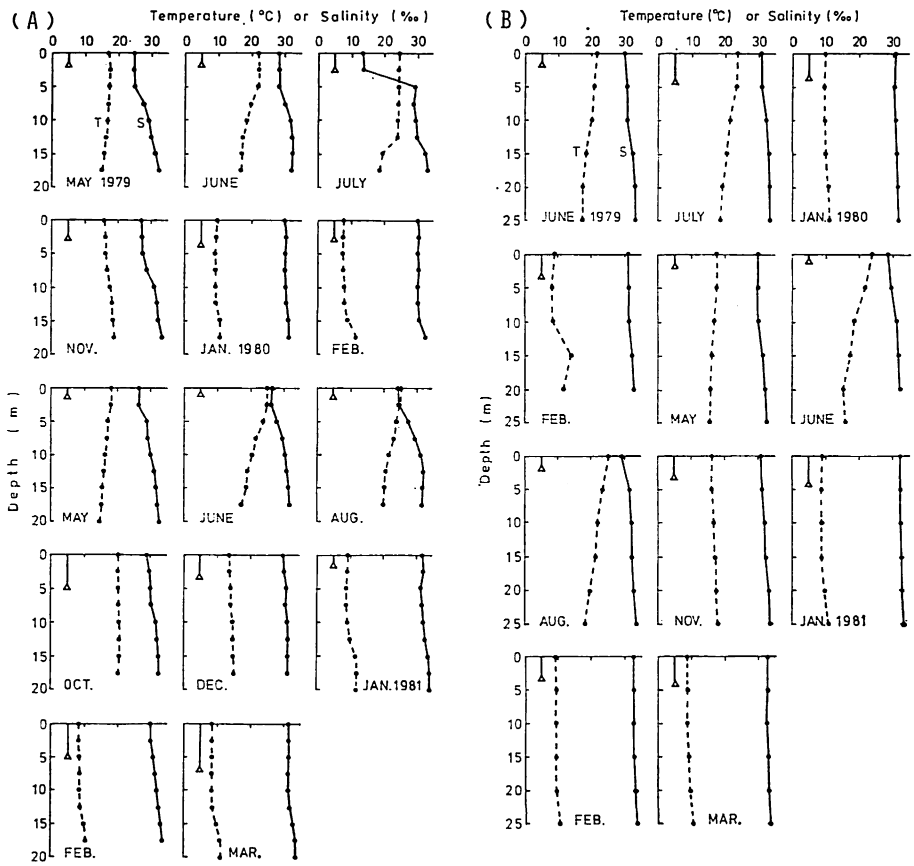


Fig. 2. Vertical profiles of temperature (dotted lines) and salinity (solid lines), and the Secchi disc depth (open triangles) at Stns. A (A) and T-4 (B) in Tokyo Bay.

tween the two stations. A not well-defined thermal stratification could be seen from May to August, breaking down during winter when vertical mixing takes place. Temperature at both the surface and the bottom was lower in the innermost part of Tokyo Bay than in Uraga Strait during winter and higher during summer. The same situation was observed by the MINISTRY OF TRANSPORTATION (1979).

Salinity of the surface water at Stn. A is influenced to a great extent by the freshwater discharged from River Tamagawa. It ranged from 13.4 to 30.8‰. Usually, less saline water was found in the upper layer and a more saline watermass of oceanic origin was always present near the bottom. During the autumn-winter period the oceanic influence seems to be stronger and salinity higher than 30‰ was measured even in more superficial layers.

The transparency at Stn. A was higher during the autumn-winter period than during the spring-summer period, varying from 1 to 5 m. It ranged from 1.5 to 6.5 m at Stn. T-4.

Fig. 3 shows seasonal variations of nutrient concentrations in the surface water at Stn. A. Total inorganic nitrogen concentration ranged from 9.9 to 73.8 μg-at./l and silicate concentration from 0 to 72 μg-at./l. Phosphate was present always in lower concentrations than inorganic nitrogen and silicate, ranging from 0.12 to 1.9 μg-at./l. Comparatively low concentrations of nutrients were found at the end of August 1979 and in June 1980 probably due to consumption by the phytoplankton population which was very large during those periods.

The vertical distribution of ammonium and nitrate was not uniform, showing a not well-defined seasonal trend (Fig. 4(A)). Nitrite and phosphate were present in small amounts and almost uniformly distributed in the water column. Silicate was always present in high concentrations in the whole water column especially in 1979 (Fig. 4(B)) with the exception of August when the diatom population was very large. In February 1980 the silicate concentration decreased to not detectable values. The seasonal trend of silicate distribution was also not defined and the vertical distribution was not uniform.

Horizontal distributions of total inorganic nitrogen, phosphate and silicate in different periods of 1980 are indicated in Fig. 5. In general, very high concentrations were observed in the inner part of the bay and the concentrations decreased in Uraga Strait toward the mouth of Tateyama Bay. A similar pattern of nutrient distribution was

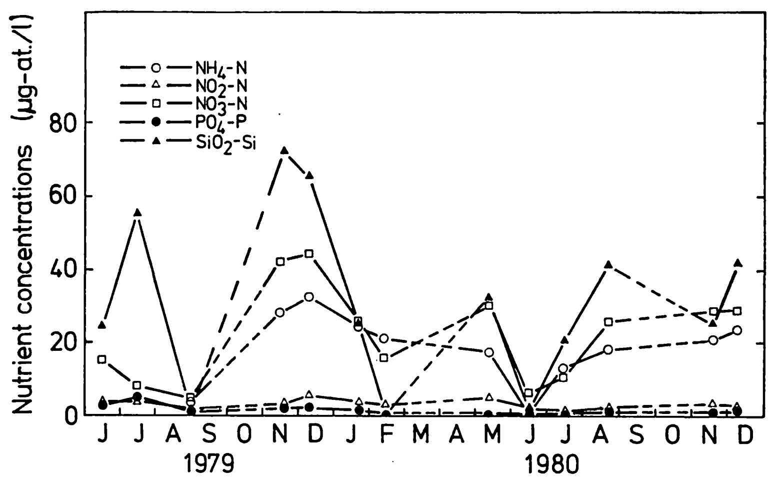


Fig. 3. Seasonal variations of nutrient concentrations in the surface water at Stn. A in Tokyo Bay.

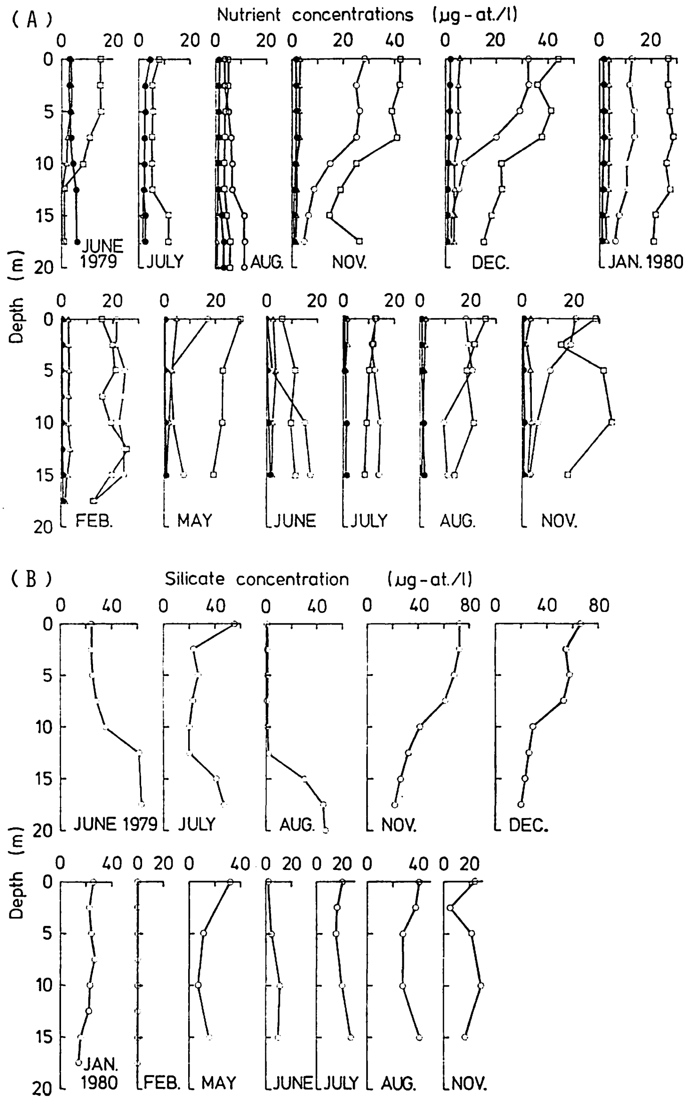


Fig. 4. Vertical profiles of ammonium (○), nitrite (△), nitrate (□) and phosphate (●) concentrations (A) and of silicate concentration (B) at Stn. A in Tokyo Bay.

observed by ICHIMURA (1967) and FUNAKOSHI (1973) in the surface water of Tokyo Bay.

2. Seasonal Variations of Phytoplankton Biomass

Seasonal variations of the cell number of phytoplankton in the surface water at Stn. A are indicated in Fig. 6. The cell number varied irregularly throughout the sampling period, ranging from 5.3×10^3 to 8.2×10^4/m*l*. It was high in May, August and February, but low in June and January. From May 1979 until February 1980, 39 species of diatoms and 24 species of dinoflagellates were observed, but only the frequent groups are indicated in Table 1. Some Chlorophycean, Euglenophycean and Crysophycean algae were also present but in small number. Except in May and July, diatoms dominated over dinoflagellates and the most frequent species was *Skeletonema costatum*, occurring abundantly in different periods of the year; e.g. 4.97×10^4/m*l* in August and 4.95×10^4/m*l*

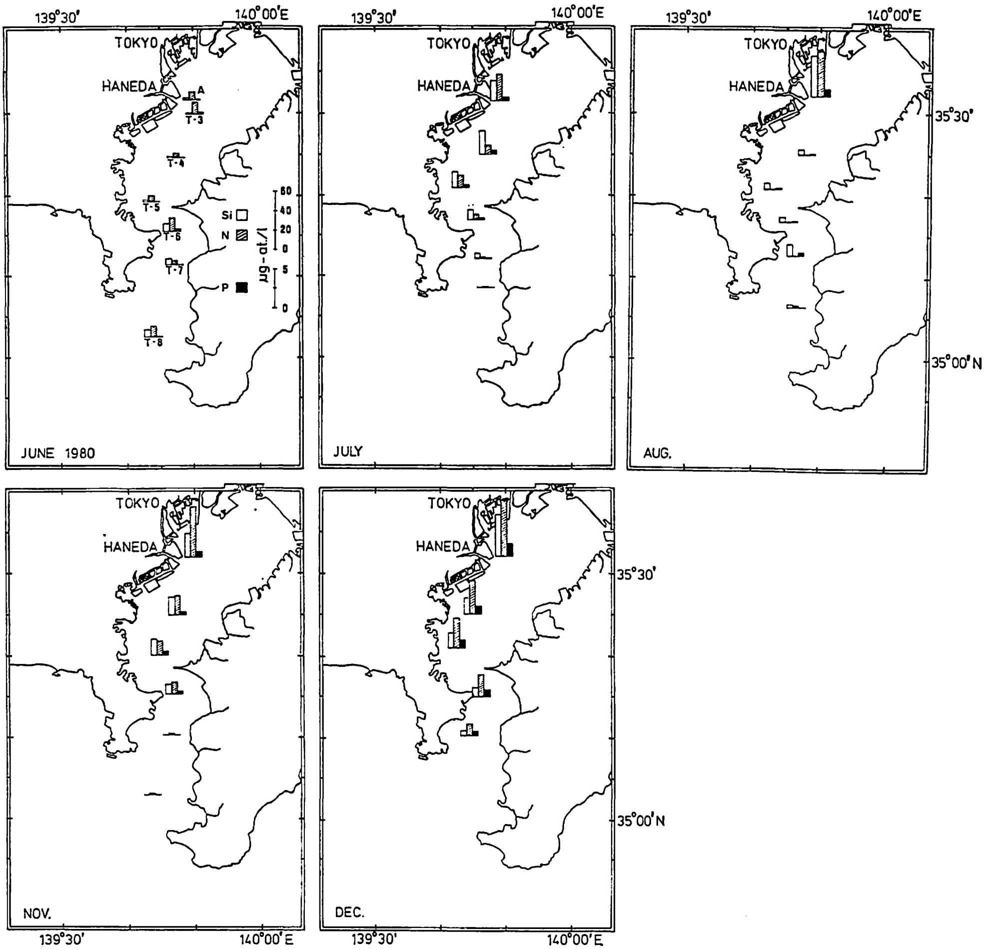


Fig. 5. Horizontal distributions of total inorganic nitrogen, phosphate and silicate in the surface water of Tokyo Bay (June—December 1980).

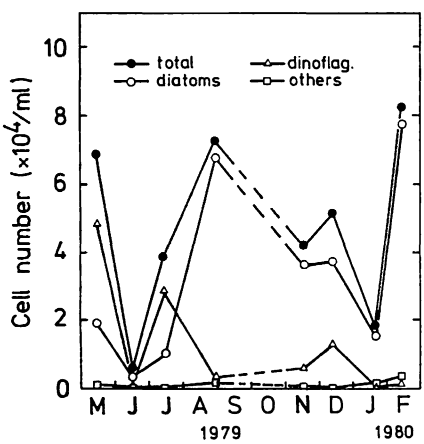


Fig. 6. Seasonal variations of the phytoplankton cell number in the surface water at Stn. A in Tokyo Bay.

in February. These values are very similar to $5\times10^3-10^4$/m*l* reported by MARUMO *et al.* (1974) for maximal growth period in June and August of 1972. In November 1979 the dominance was replaced by *Chaetoceros curvisetum*. Both *S. costatum* and *C. curvisetum* dominated the diatom population in January, but in February *S. costatum* again became the most frequent species followed by *Thalassiosira decipiens* and *T. anguste-lineata.* Among the dinoflagellates, *Prorocentrum minimum* was the dominant in May being replaced by *Prorocentrum triestinum* from July until January. In February *Peridinium* spp. were the most abundant.

The chlorophyll *a* concentration in the surface water of Stn. A (cf. Fig. 10(A)) was

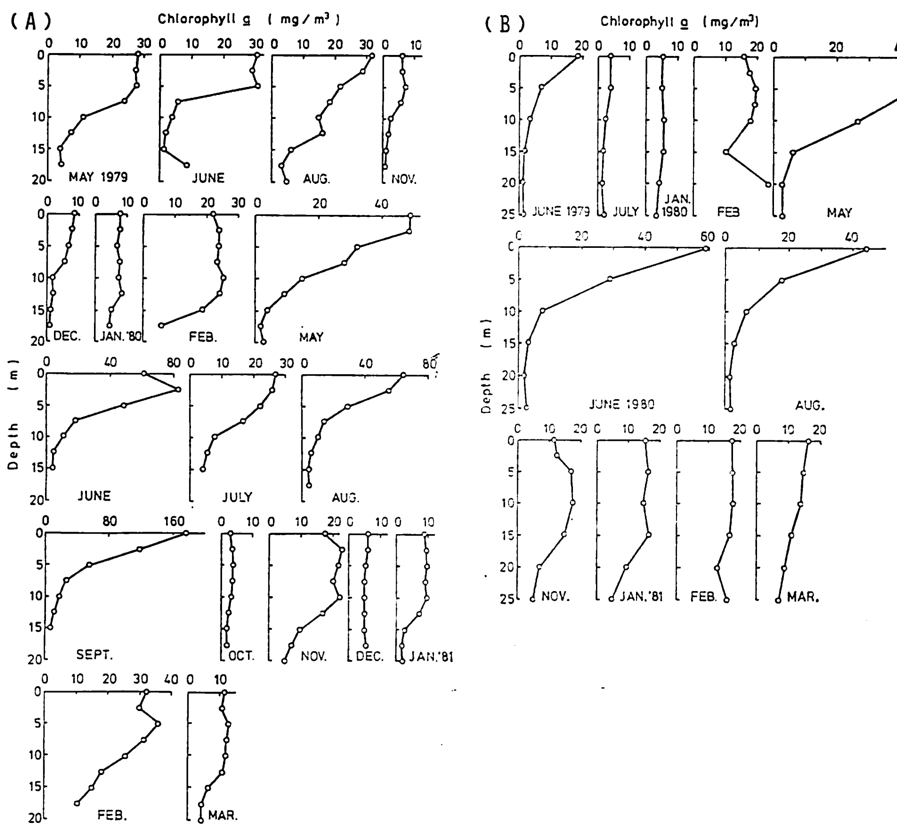


Fig. 7. Vertical profiles of chlorophyll *a* concentration at Stns. A (A) and T-4 (B) in Tokyo Bay.

high during summer except in July and low from October through January, ranging from 2.72 to 175 mg/m^3 throughout the year. The maximum value of 175 mg/m^3 was obtained in September 1980.

The vertical profiles of chlorophyll *a* at Stns. A and T-4 are illustrated in Fig. 7. It was high at the surface during the warm seasons with decrease toward the bottom, while during the vertical circulation periods of winter it was comparatively low and uniformly distributed in the water column. Subsurface peaks were observed in June 1979 and 1980. A careful comparison of Fig. 7 with Fig. 2 indicated that the surface layer with high chlorophyll *a* concentrations became thicker from May to September as the thermocline became deeper. This trend seems to be closely related to the vertical mixing of water between the surface and the deeper layers.

In the same area in Tokyo Bay, ICHIMURA and KOBAYASHI (1964) obtained chlorophyll *a* concentrations of 10–200 mg/m^3 and ICHIMURA (1967) found concentrations higher than 100 mg/m^3 during summer 1963. Similar concentrations of chlorophyll *a* were obtained 10 years later by YAMAGUCHI and ICHIMURA (1976), and a maximum of 104.7 mg/m^3 was reported in summer of 1978 by SHIBATA and ARUGA (1982). The range of chlorophyll *a* concentration observed during the present work was similar to those reported by these authors.

The horizontal distributions of chlorophyll *a* in the surface water from the inner bay through Uraga Strait are shown in Fig. 8. In general, independent of the seasons, higher concentrations of chlorophyll *a* were found in the inner bay, decreasing rapidly

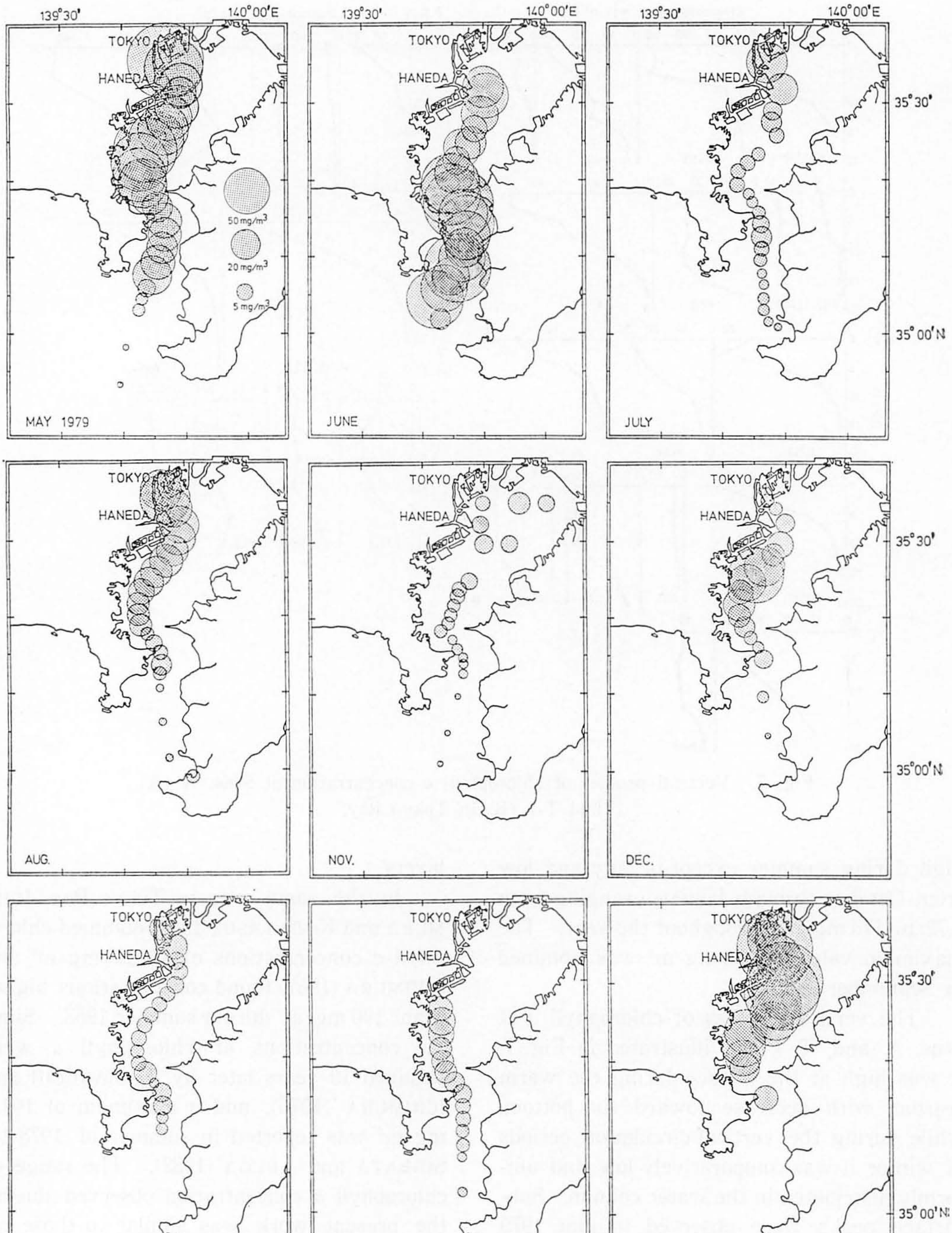
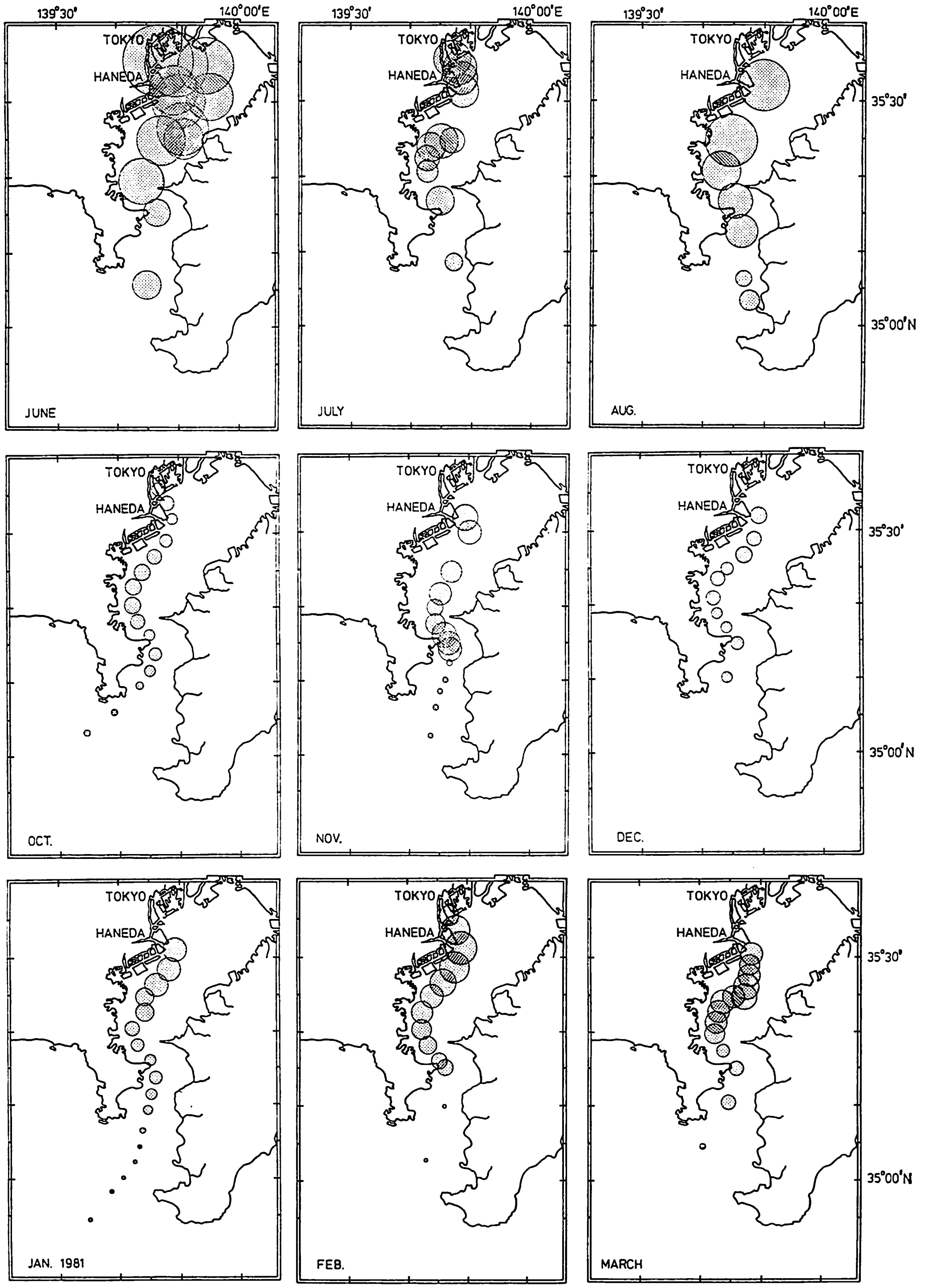


Fig. 8. Horizontal distributions of chlorophyll *a* concentration in the surface water of Tokyo Bay (May 1979—March 1981).


139°30'
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TOKYO
HANEDA
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AUG.
OCT.
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JAN. 1981
FEB.
MARCH

Table 1. Abundance of phytoplankton species in the surface water at Stn. A from May 1979 to February 1980 ($\times 10^3$ cells/ml).

Species	1979						1980	
	May	June	July	Aug.	Nov.	Dec.	Jan.	Feb.
Chaetoceros curvisetum				3.6	**29.5**	r	5.4	
C. decipiens				1.9				
C. didymus				0.5				1.3
C. spp.							0.9	0.5
Coscinodiscus spp.				0.6	r	r	0.1	
Cyclotella sp.		0.6						
Ditylum brightwelii				0.2			0.4	0.3
Eucampia zoodiacus			1.8		0.1		0.35	1.6
Nitzschia closterium				1.1				0.2
N. seriata	0.75			6.1		0.4	0.3	
N. sp.	0.13							1.5
Rhizosolenia fragilissima							0.3	0.3
Skeletonema costatum	**17.5**	1.8	7.6	**49.7**	4.4	**35.5**	5.3	**49.5**
Thalassiosira anguste-lineata					r			6.5
T. binata				1.8				
T. decipiens				0.2	1.3		0.9	**10.8**
T. rotula					r	r		2.4
T. spp.	1.0	1.15		1.0		1.2		1.9
Dinophysis sp.		0.1		0.3				
Gymnodinium sp.	0.6	0.05						0.4
Peridinium minusculum	0.13		0.1	0.1				0.2
P. spp.	0.13	0.15	2.3	0.2	r	0.1		1.8
Phalacroma sp.	0.25	0.15						0.1
Prorocentrum micans	0.25	0.45						
P. minimum	**46.7**	0.25			0.7	0.5	0.1	0.5
P. triestinum			**26.4**	2.0	5.1	**12.9**	0.7	0.1
Dictyocha fibula				0.1			0.2	
Distephanus speculum							1.3	3.5
Euglena sp.	0.25			1.9				
Eutreptiella sp.	0.6	0.45	0.1					

r: rare

from Uraga Strait toward the open sea. The geographical as well as seasonal patterns of distribution of the phytoplankton biomass were not so clear. Although very high and variable concentrations of chlorophyll *a* were observed during the warm seasons and comparatively low and uniform concentrations in the cold periods of the year, high concentrations of chlorophyll *a* could be observed sometimes in winter and low concentrations in summer.

SHIBATA and ARUGA (1982) also found a great variability in the surface chlorophyll *a* concentrations over the whole area of the bay and YAMAGUCHI and SHIBATA (1979) recognized no definite pattern of horizontal chlorophyll *a* distribution in the bay. YAMAGUCHI and ICHIMURA (1976) reported that the chlorophyll *a* concentrations were 10 to 50 times more variable than those previously obtained in the region off Haneda (ICHIMURA 1967) due to the increasing eutrophication of the bay.

3. *Seasonal Variations of Phytoplankton Photosynthesis*

Photosynthesis-light curves of the surface phytoplankton samples obtained at Stn.

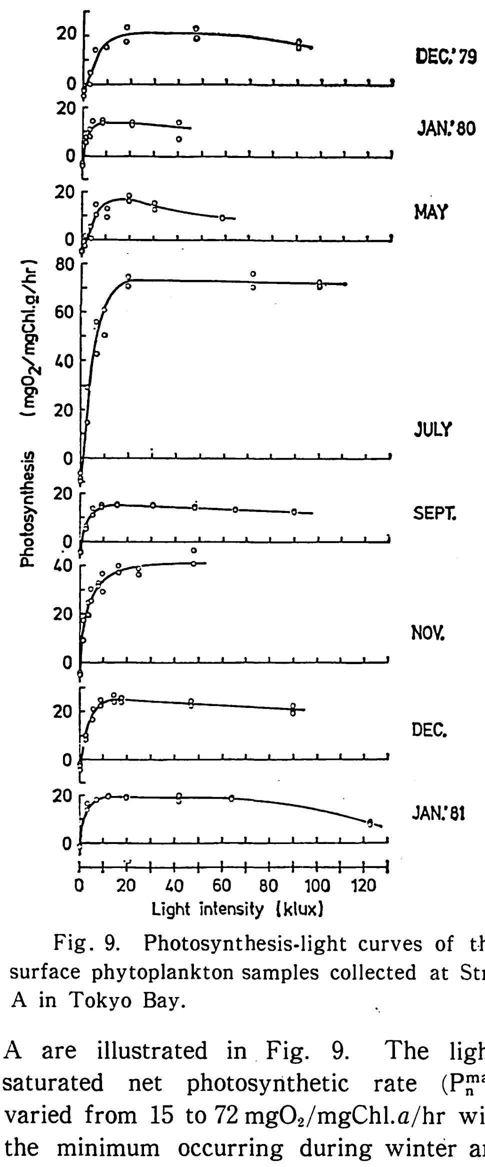

Fig. 9. Photosynthesis-light curves of the surface phytoplankton samples collected at Stn. A in Tokyo Bay.

A are illustrated in Fig. 9. The light-saturated net photosynthetic rate (P_n^{max}) varied from 15 to 72 mgO_2/mgChl.*a*/hr with the minimum occurring during winter and the maximum during summer. In January 1980 a shade type photosynthesis-light curve was obtained reaching the P_n^{max} at approximately 6 klux, while in July a sun type curve was obtained reaching the P_n^{max} at about 20 klux without the inhibition of photosynthetic rate even at very high light intensities. In September the photosynthesis-light curve showed the shade type, but in November and December the curves were something between shade and sun type. In January 1981 again the photosynthesis-light curve became the shade type with the P_n^{max} at 10 klux.

Using the Winkler method, HOGETSU *et al.* (1959) obtained P_n^{max} of 24-45 mgO_2/mgChl.*a*/hr with surface samples of *Skeletonema* in the region off Haneda. They did not observe the inhibition of photosynthesis at high light intensities up to 140 klux. ICHIMURA and ARUGA (1964) reported a photosynthesls-light curve of *Thalassiosira* and *Skeletonema* bloom in Tokyo Bay which had no inhibition of photosynthesis. FUNAKOSHI (1973) also obtained the photosynthesis-light curves of phytoplankton without intense light inhibition in Tokyo Bay. However, SHIBATA and ARUGA (1982) reported the inhibition of photosynthetic rate in their phytoplankton samples from the surface water off Haneda especially during summer.

Although only a few curves were obtained during the present work, they showed similar seasonal characteristics in comparison with those reported previously by other workers in Tokyo Bay concerning the range of P_n^{max} values (HOGETSU *et al.* 1959, FUNAKOSHI 1973, SHIBATA and ARUGA 1982), no inhibition of photosynthesis at high light intensities during summer (HOGETSU *et al.* 1959, ICHIMURA and ARUGA 1964, FUNAKOSHI 1973) and the differentiation of photosynthetic pattern into sun and shade types in different periods of a year (ICHIMURA and ARUGA 1964).

Fig. 10 (B and C) shows the seasonal variations of photosynthesis and respiration of the surface phytoplankton samples obtained at Stn. A. Gross and net photosynthetic rate both on a water volume basis and on a chlotophyll *a* basis showed a similar pattern of seasonal variations. Gross photosynthetic activity on a water volume basis showed a maximum of 2.98 mgO_2/l/hr in September 1980 and a minimum of 0.08 mgO_2/l/hr in January 1981. Respiratory activity on a water volume basis was fairly high during the warmer seasons (May-October). Gross photosynthetic rate on a chlorophyll *a* basis ranged from 9.52 to 80 mgO_2/mgChl.*a*/hr; the highest value was obtained in July 1980 and the lowest in January 1981.

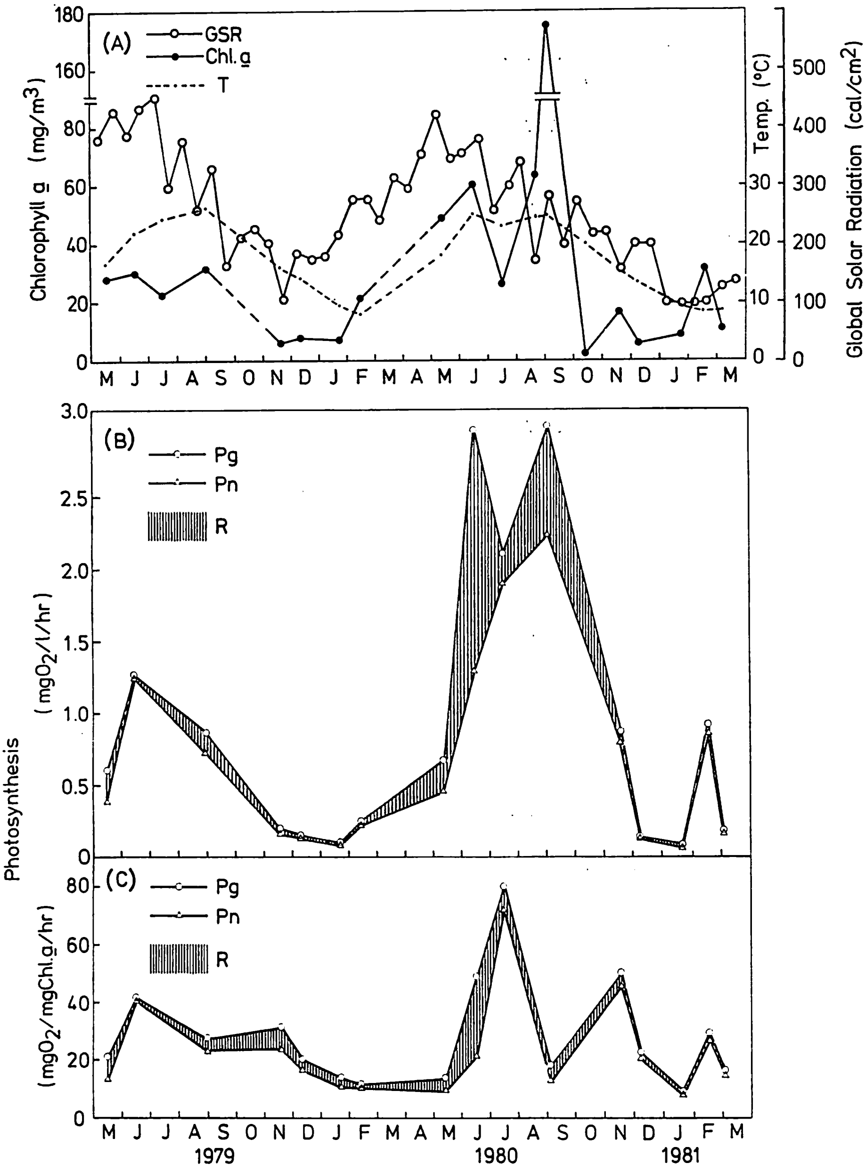

Fig. 10. Seasonal variations of chlorophyll *a* concentration (A), light-saturated photosynthesis and respiration activity (B and C) of phytoplankton from the surface water of Stn. A in Tokyo Bay. P_g, gross photosynthesis; P_n, net photosynthesis; R, respiration. Surface water temperature (T) and global solar radiation (GSR) are also illustrated. GSR data are averaged for each half-month period in Tokyo based on JAPAN METEOROLOGICAL AGENCY (1979-1981).

The horizontal distribution of gross photosynthetic rate was obtained only in the inner bay from June to December 1980 (Fig. 11). Gross photosynthetic rates were high and varied from 15.3 to 71.9 mgO_2/mgChl.*a*/hr during summer and from 11.0 to 46.2 mgO_2/mgChl.*a*/hr during autumn-winter period, showing no definite pattern of distribution. FUNAKOSHI *et al.* (1974) obtained values of 1.5-15 mgO_2/mgChl.*a*/hr in the areas from the innermost part of the bay to the outside oceanic region. In recent

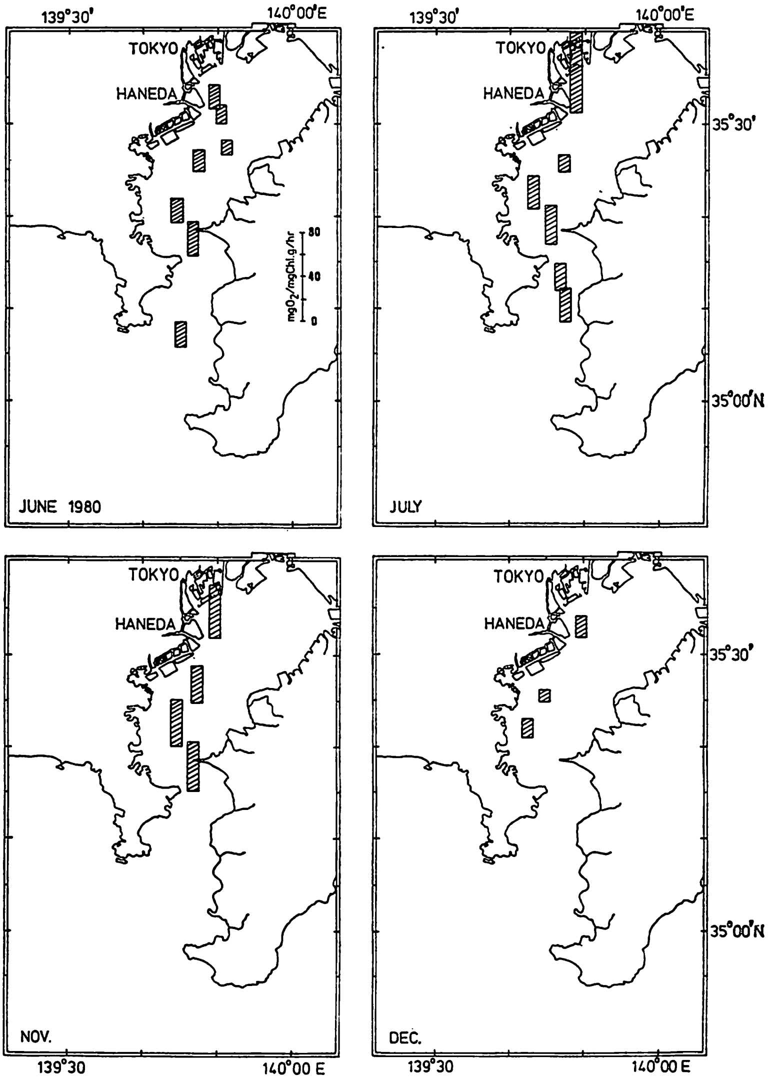

Fig. 11. Horizontal distributions of light-saturated gross photosynthesis of surface phytoplankton samples in Tokyo Bay (June—December 1980).

years the light-saturated net photosynthetic rates from 7.4 to 56 mgO_2/mgChl.*a*/hr were reported for the surface samples in Tokyo Bay by ARUGA and SHIBATA (1978) and SHIBATA and ARUGA (1982).

The vertical distributions of light-saturated photosynthesis and respiration at Stn. A are shown in Fig. 12. In general, the photosynthetic activity on a water volume basis was high in surface samples and low in deeper samples, decreasing with depth. The pattern of vertical distribution mostly followed that of chlorophyll *a*. Gross and net photosynthesis ranged from 0.014 to 2.95 and from 0.0044 to 1.88 mgO_2/l/hr, respectively. On a chlorophyll *a* basis, light-saturated gross and net photosynthesis ranged from 3.21 to 80 and from 1.69 to 72 mgO_2/mgChl.*a*/hr, respectively. In some cases they decreased with depth, but in general they were vertically at a similar level even in deeper samples. During the periods of vertical circulation, both the photosynthesis activity on a water volume basis and that

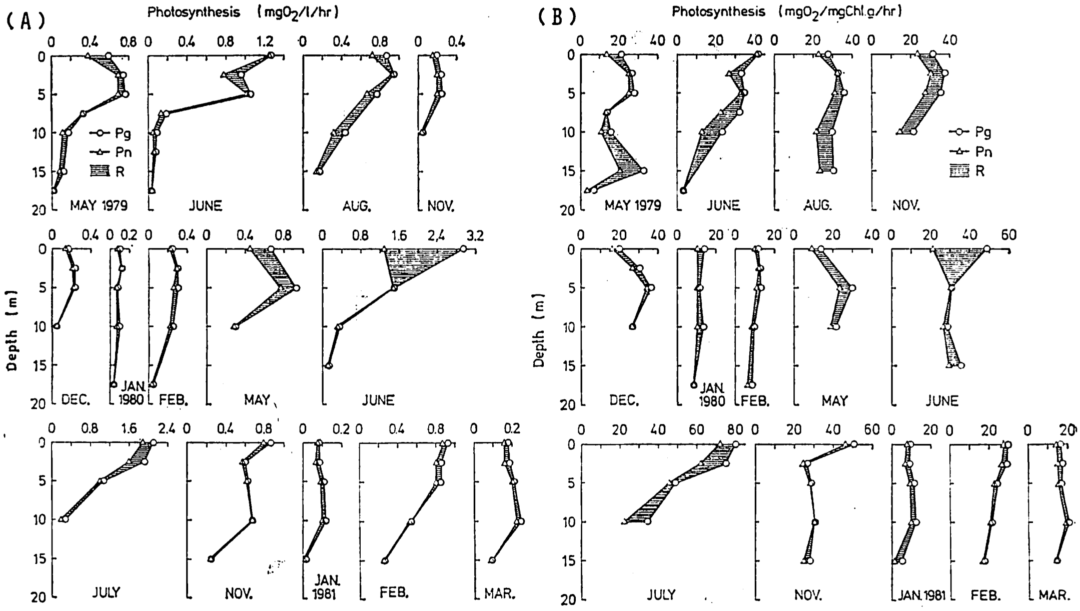

Fig. 12. Vertical profiles of light-saturated photosythesis and respiratory activity of phytoplankton samples collected from different depths at Stn. A in Tokyo Bay. P_g, gross photosynthesis; P_n, net photosynthesis; R, respiration. (A), on a water volume basis and (B), on a chlorophyll *a* basis.

on a chlorophyll *a* basis were almost uniformly distributed in the water column. Subsurface maximum of photosynthesis activity was sometimes observed even in winter samples.

The respiratory rate obtained in the present study, of course, includes zooplankton and bacterial respiration which is reported to be very high during summer (TSUJI *et al.* 1974, SEKI *et al.* 1974). In the present study, as indicated in Fig. 10, it was also higher during the warm seasons than in winter, ranging from 0.015 to 1.66 mgO_2/l/hr. The seasonal variations of respiratory activity on a chlorophyll *a* basis were not so clear; the rate ranged from 0.75 to 27.49 mgO_2/mgChl.*a*/hr. In the vertical profiles (Fig. 12), the respiration activity was usually higher on a water volume basis in the surface samples especially during summer, but on a chlorophyll *a* basis higher rates were often observed in deeper samples.

4. *Relationships of Phytoplankton Biomass and Photosynthesis to Environmental Factors*

(a) Temperature and Solar Radiation

It is very difficult to analyse the relationships between phytoplankton production and environmental factors especially in highly eutrophic areas such as Tokyo Bay. The results obtained in the present investigation clearly indicated that chlorophyll *a* concentrations and photosynthetic rates tend to increase during summer and to decrease during winter. Although comparatively large quantities of chlorophyll *a* were measured in February 1980 and 1981, chlorophyll *a* concentrations lower than 20 mg/m^3 were never observed from May to August 1979 and from May to September 1980 (Fig. 10(A)).

The role of temperature in controlling the seasonal variation of phytoplankton primary production in shallow and temperate eutrophic estuaries has been pointed out by several workers (WILLIAMS and MURDOCH 1966, EPPLEY 1972, HARRIS and PICCININ 1977). However, the dependency of primary production on temperature in the region off Haneda in Tokyo Bay is still not completely clear presumably due to the extremely advanced eutrophication making the seasonal

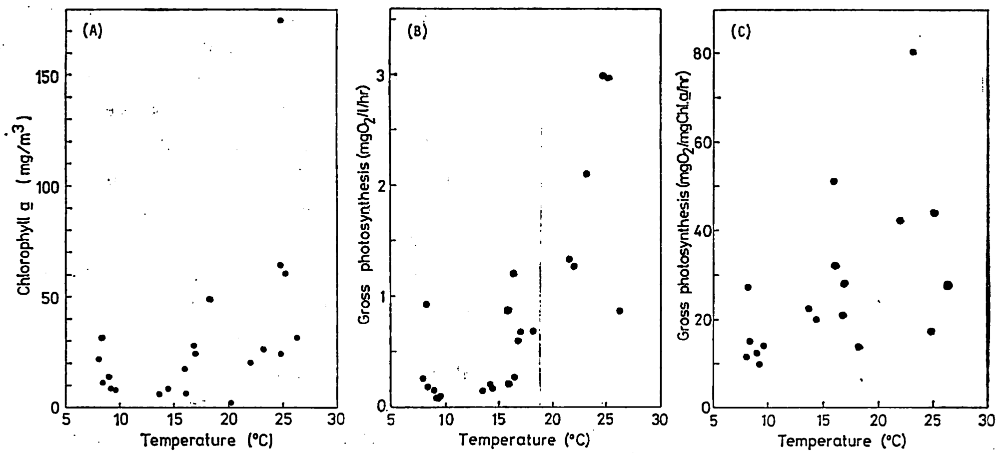

Fig. 13. Relationship of chlorophyll *a* concentration (A) and light-saturated gross photosynthesis (B and C) to temperature of the surface water at Stn. A in Tokyo Bay.

variation of phytoplankton production difficult to be detected (YAMAGUCHI and SHIBATA 1979).

Fig. 13 shows the relationships of chlorophyll *a* concentration, gross photosynthesis on a water volume basis and gross photosynthesis on a chlorophyll *a* basis to temperature in the surface water at Stn. A. Relatively higher correlation in the case of photosynthesis on a water volume basis (Fig. 13(B)) might have resulted from compound effects of temperature and chlorophyll *a* concentrations. The scattering of points in Fig. 13 may be interpreted as the result of interference by environmental factors other than temperature; e.g. SINCLAIR *et al.* (1981) observed that short-term variations of phytoplankton biomass may be related to changes in the density profiles of the water column in many estuaries during periods in which growth is not limited by light. HARRIS *et al.* (1980), who also did not observe a clear relationship between P^{max} and temperature, pointed out that photosynthetic rate responds better to the changes in the ratio of the depth of euphotic zone to the depth of mixed layer (Z_{eu}/Z_m) than to only temperature. It is clear from Fig. 13(C) that the correlation between both parameters is less pronounced during the warm periods of a year. According to HARRIS *et al.* (1980), the unstable meteorological conditions during summer in Hamilton Harbour (L. Ontario) probably affect the physical regimes of the water column and consequently rapid changes in the Z_{eu}/Z_m ratio may occur followed by changes in P^{max}. If this is also the case in Tokyo Bay, the absence of a clear correlation between photosynthesis activity of phytoplrnkton and temperature observed in the present study as well as by other workers (cf. SHIBATA and ARUGA 1982) could be partially explained.

The seasonal variations of surface chlorophyll *a* concentration at Stn. A and solar radiation showed a fairly good correlation as can be seen in Fig. 10(A). It seems that not only temperature but also the yearly changes of solar radiation may affect the seasonal variations of phytoplankton growth in Tokyo Bay. It would probably be more reasonable to consider the combined effects of light and temperature regimes in controlling the seasonal changes of phytoplankton biomass in the region off Haneda, instead of analysing the relationships of these environmental factors to phytoplankton production separately. Correlations of phytoplankton production to both solar radiation and temperature changes have also been found by other workers in estuaries (SCOTT 1979) and freshwater environments (JONES 1977a, b).

(b) Salinity

Clear relationships could not be observed

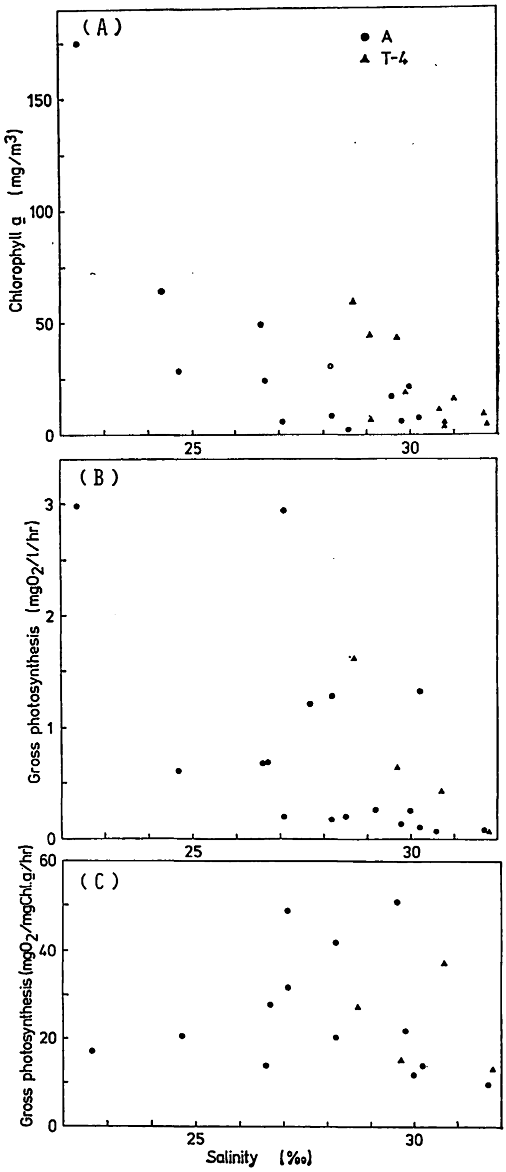

Fig. 14. Relationships of chlorophyll *a* concentration (A) and light-saturated gross photosynthesis (B and C) to salinity of the surface water at Stns. A and T-4 in Tokyo Bay.

of chlorophyll *a* concentrations and gross photosynthesis to salinity of the surface water at Stns. A and T-4 in the present study (Fig. 14). An optimum salinity of 25‰ was reported by NAKANISHI and MONSI (1965) for phytoplankton growth in Tokyo Bay. SHIMURA *et al.* (1979) found a tolerance of *Skeletonema costatum* and *Chaetoceros* sp. to salinity variations in the range of 4.4 to 40.0‰. A similar range of tolerance was observed for *Thalassiosira decipiens* by TAKANO (1963). These species were the principal components of the diatom population at Stn. A from May 1979 through February 1980 in the present investigation (cf. Table 1). With the exception of July 1979, the range of salinity variation in the surface water at Stn. A was from 22.4 to 30.8‰. These values are consistent with the favorable salinity ranges reported by the authors mentioned above. Therefore, it may be considered that the salinity was adequate for the development of phytoplankton population in the area concerned during most of the period of the present work.

Relationship between chlorophyll *a* concencentration and salinity of the surface water in the inner part of Tokyo Bay and Uraga Strait is shown in Fig. 15. Chlorophyll *a* concentration tended to decrease as the salinity increased; the concentration was higher in the inner part of the bay than in Uraga Strait and the salinity was lower in the former than in the latter. SHIBATA and ARUGA (1982) observed higher photosynthetic rates followed by lower salinity in the inner part of Tokyo Bay and lower photosynthetic rates followed by higher salinity in Uraga Strait. A similar trend was obtained by TERADA *et al.* (1974) in the eutrophic estuary of Shimoda Bay. During the present work, however, higher salinities were associated with the low temperature periods and also with the lowest concentrations of nutrients in the mouth of the bay (cf. Fig. 5). Therefore, the relationships of biomass and photosynthesis to salinity obtained in the present work should be carefully examined in due consideration of the interactions of other environmental factors. Unfortunately, photosynthesis-salinity curves were not obtained in the present study, but certainly they would have been helpful for a more precise comprehension of these relationships.

(c) Nutrients

No correlation was observed between seasonal changes in the chlorophyll *a* con-

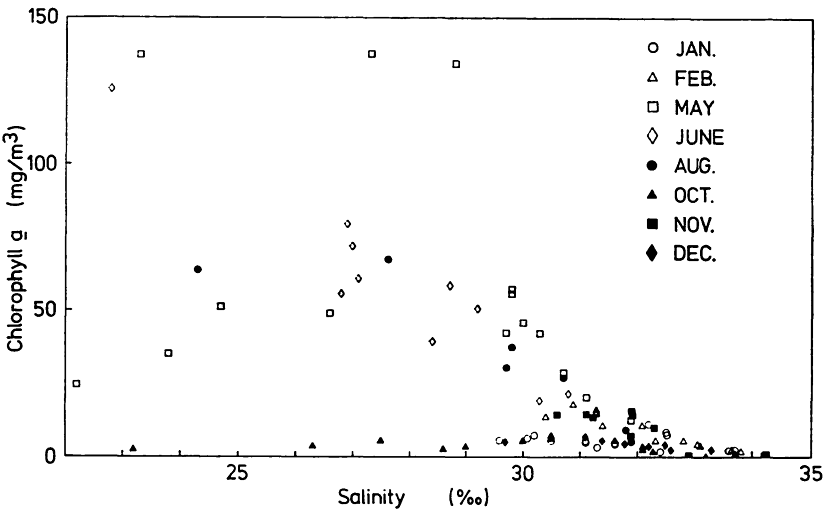

Fig. 15. Relationship between chlorophyll *a* concentration and salinity of the surface water in Tokyo Bay and Uraga Strait.

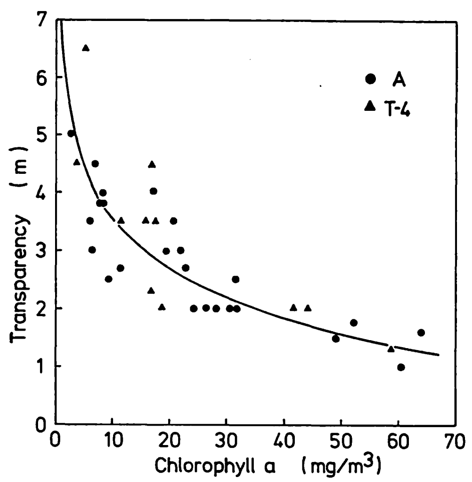

Fig. 16. Relationship between surface chlorophyll *a* concentration and transparency (Secchi disc depth) at Stns. A and T-4 in Tokyo Bay.

centrations and nutrients as well as between those in the photosynthetic rates and nutrients (cf. Figs. 3 and 10). There were not well-defined annual variations of total inorganic nitrogen, phosphate and silicate concentrations which were always high enough to support well-growing phytoplankton populations in the estuarine region off Haneda throughout the year (cf. NAKANISHI and MONSI 1965, ICHIMURA 1967, FUNAKOSHI *et al.* 1974) with the exception of silicate which might have been limiting the diatom development in August 1979 and February and June 1980.

(d) Transparency

A very clear hyperbolic relationship was obtained between transparency (Secchi disc depth) and chlorophyll *a* concentration in the surface water at Stns. A and T-4 (Fig. 16). A similar relationship was reported by SHIBATA and ARUGA (1982) with the data from the whole area of the bay and also by TOYOTA and NAKASHIMA (1979) with the data from Uraga Strait and Sagami Bay. It is evident that the transparency is strongly affected by the amount of chlorophyll in water (cf. ICHIMURA 1956, SAIJO and ICHIMURA 1960).

(e) Tide

Unfortunately, the effect of tide on the diurnal changes of chlorophyll *a* concentrations in water was not studied in the present work; however, it should be taken into account especially in estuarine regions. Short-term temporal variations of chlorophyll *a* concentration have been noted together with changes in physical and chemical properties in Tokyo Bay (ARUGA and SHIBATA 1978, MINISTRY OF TRANSPORTATION 1979); the concentration of chlorophyll *a* tended to be higher during high tide and to be lower during low tide at a fixed station. These changes followed by the change in tide level might be related to the supply of river water, to the outflow of inner bay water into Uraga Strait, or to the inflow of open sea water into the inner bay.

Concluding Remarks

The results obtained in the present investigation are consistent with those reported previously by many investigators. Chlorophyll *a* concentrations found in the inner bay were by far higher than those reported for coastal areas adjacent to the Kuroshio Current and oceanic areas of the Pacific Ocean (SHIMURA and ICHIMURA 1972, TAKAHASHI *et al.* 1972, ICHIMURA 1980). The high levels of chlorophyll *a* concentration and of photosynthetic activity of phytoplankton observed from May 1979 to March 1981 reflect the eutrophic conditions in Tokyo Bay. Highly productive periods showed higher phytoplankton biomass and photosynthetic activity in 1980 than in 1979.

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F. P. ブランジーニ・有賀祐勝：東京湾における植物プランクトンの現存量および光合成活性と環境条件

1979年5月〜1981年3月に東京湾内湾と浦賀水道で19回の調査を行った。Stn. A では，植物プランクトン細胞数は 5.3×10^3〜8.2×10^4/ml で，5，8，2月に多く，6，7月に少なかった。主な優占種は *Skeletonema costatum* と *Prorocentrum* spp. であった。表面水中のクロロフィル *a* は 2.7〜175 mg/m^3 で，1980年9月に最大値が得られ，10〜1月には比較的少なかった。光飽和総光合成は 0.08〜2.98 mgO_2/l/hr (9.5〜80 mg O_2/mg Chl. *a*/hr) で，水体積当りでは1980年9月に最高，1981年1月に最低であったが，クロロフィル *a* 当りでは夏季に高く，冬季に低かった。クロロフィル *a* 濃度と光合成活性は，高温期に高く，低温期に低い傾向があるものの，温度との相関はあまり明確でなかった。クロロフィル *a* 濃度は，低塩分の内湾で高く，高塩分の浦賀水道で低かったが，光合成活性と塩分の関係は明らかでなかった。また，クロロフィル *a* 濃度と栄養塩濃度との間にも明確な関係は認められなかった。（〒108 東京都港区港南 4-5-7　東京水産大学水産植物学教室）