PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

XVI. THE PLANKTON OF TÔKYÔ BAY IN RELATION TO THE WATER MOVEMENT[1]

ISAMU YAMAZI
Seto Marine Biological Laboratory, Sirahama

With Plates XIX–XX and 22 Text-figures

General oceanographical observations of Tôkyô Bay were already made by KOBE MARINE OBSERVATORY (1931). After the war, the Central Fisheries Experimental Station made also the oceanographical and biological surveys with special reference to the productivity (HANAOKA *et al.*, 1947–1950; HANAOKA, 1952). The planktological communities of the bay have been studied by AIKAWA (1936), FUJIYA (1952) and SHIMOMURA (1953). The benthic communities have been studied by MASUI (1943), KAWAGUCHI (1946), SHIMAZU and YAMANE (1948) and HABE (1952).

The present paper deals mainly with the regional distribution of the plankton with reference to the hydrological environment, and comments on the surface water mass movements of the bay are made from the planktological viewpoint. The materials and oceanographical data on which the present paper is based owe to the investigations by HANAOKA *et al.* (1947–1950).

I want to express my sincere gratitude to Dr. T. HANAOKA, director of the Naikai Regional Fisheries Research Laboratory, who made it possible for me to use plankton material and supplied me with the necessary hydrological data for the period of the survey.

The materials on which the present paper is based were collected between the 4th to 9th of July, 1948, by means of KITAHARA's quantitative tow-net with MÜLLER gauze No. 13, 22.5 cm in diameter of mouth and 50 cm in that of the widest part, as hauled vertically from bottom or 50 m to the surface. Among plankton organisms, chaetognaths will be described fully in another paper by Mr. A. MURAKAMI of the Naikai Regional Fisheries Research Laboratory. The plankton volume of each sample was measured after settling of 24 hours. All plankton figures and data imply the volume or number per one meter haul. The stations are shown in Fig. 1.

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1) Contributions from the Seto Marine Biological Laboratory, No. 261.

General Hydrological Conditions

Tôkyô Bay has an area of about 1,187 km^2, a volume of about 16.1 km^3 and an average depth of about 13.9 m in the inner part. As shown in Fig. 1, the inner region of the bay is relatively shallow, less than 40 m, and the basin is inclined more slowly on the east than on the west. On the contrary the outer region or the entrance of the bay, namely " Uraga-suido ", is much deeper, more than 500 meters at the central part forming a drowned valley. The bay receives several large rivers, Sumida-gawa, Edo-gawa and Naka-gawa at the head, and several relatively smaller rivers at the western coast, and the coastal area thus shows very small transparency, low salinity, brown color and is highly polluted by industrial sewage. According to data given by HANAOKA *et al.*, the general hydrological conditions of Tôkyô Bay are as follows:

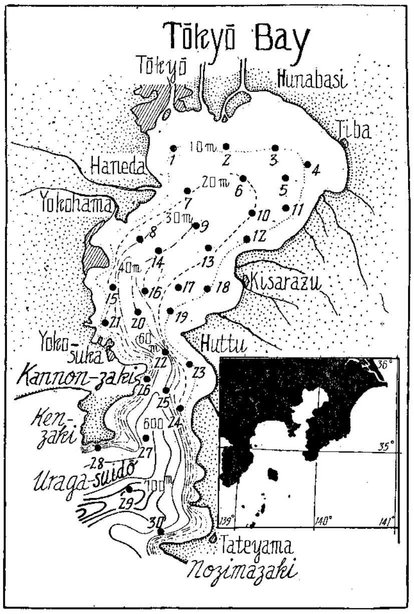

Fig. 1. Map of Tôkyô Bay, showing stations and bathymetric contours.

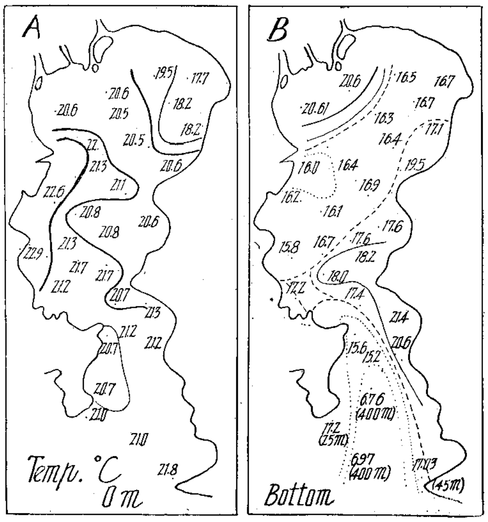

Fig. 2. Water temperature of the surface (A) and of the bottom (B) during July 4-9, 1948 (after HANAOKA, 1950).

Water temperature (Fig. 2): The water temperature at the surface is usually influenced by the air temperature. The surface temperature was between 18°C to 22.9°C. It reached the minimum at the northeastern head and became larger southwestwards. The maximum values were found near Yokohama Harbour. The water temperature at the bottom was lower than the surface. Its range was very large, being from 6°C (in 400 m depth near the mouth) to 21. 5°C. It was lower in the middle and western areas from the mouth to the central region than in the east, and it was also lower in the eastern area than in the western in the inner region of the bay. These lower temperature is correlaed with the influx of open sea waters.

Chlorinity (Fig. 3): The chlorinities in the inner and central region of the bay showed a close correlation with freshwater drainage, ranging between about 10–18‰ at the surface. The lowest value at the superficial layer was found off Tôkyô Harbour, where the estuarine water is mixed with drainage and sewage. In the subsurface waters the chlorinity showed a smaller range. Generally it was higher towards the south and east. At the northeastern corner of the inner region off Tiba, the surface chlorinity was very high as a result of progressive dilution by upwelling water from subsurface layers. In the entrance of the bay, the surface chlorinity was also high with a small range.

Currents (Fig. 4): The schematic current diagram obtained by KOBE MARINE OBSERVATORY (1931) is shown in Fig. 4. According to current observations there exist two anticlockwise currents in the inner region. The current seems to be an important factor of determining the plankton distribution, because it controls the ecological conditions. This phenomenon will be discussed later on.

Transparency (Fig. 5, A): Transparency was smaller at the northwestern corner off Tôkyô Harbour, measuring 2–2.5 m, than in the other area. This area is shallow and much polluted. This is due to the shallowness of the basin and pollution by freshwater and sewage from the neighbouring. In the entrance of the bay, however, the water is more transparent, being from 8 to 10 meters.

Water color (Fig. 5, B): The water color of the western half in the central region showed no. 8 of FOREL's scale. The water near Tôkyô was too turbid to be measured by the FOREL's scale, while towards the eastern coast it becomes clear, showing nos. 5–6 and out of the bay it showed nos. 4–5.

Oxygen content (Fig. 6): The oxygen content is largely affected by the biological conditions in various parts of the bay. In this survey the oxygen content was large at almost all stations especially in upper layers. It was smaller at the head of the bay, both the surface and bottom. The highest value existed in the central region, where the saturation degree was greater than 120% at the surface, and even in the bottom it was more than 70%. The distribution of the oxygen content was correlated with the phytoplankton populations.

Silicates (SiO_2) (Fig. 7): In general, the concentration of silicate found in the inner region was higher than in the central and outer region. Along the northern and western coast of the inner region where the river waters pour into, the silicate showed 100–3,000 mg per m^3, and decreased towards the offing. In the outer region it was only slightly traceable. As shown in Fig. 7, B and C, the silicate content in the central region was fairly uniform from surface to bottom. In the deeper layer also it was higher in the inner region as in the surface layer.

Phosphates (P_2O_5) (Fig. 8): The phosphates at the superficial and 8–10 m layers was very low throughout the stations. The relatively higher values were found at the bottom, especially in the outer region of the bay.

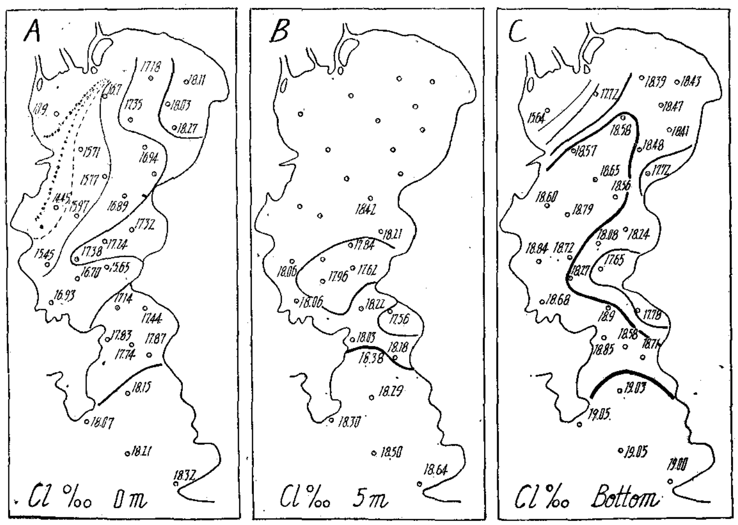

Fig. 3. Distribution of chlorinity of the surface layer (A), of the 5 m layer (B) and of the bottom (C).

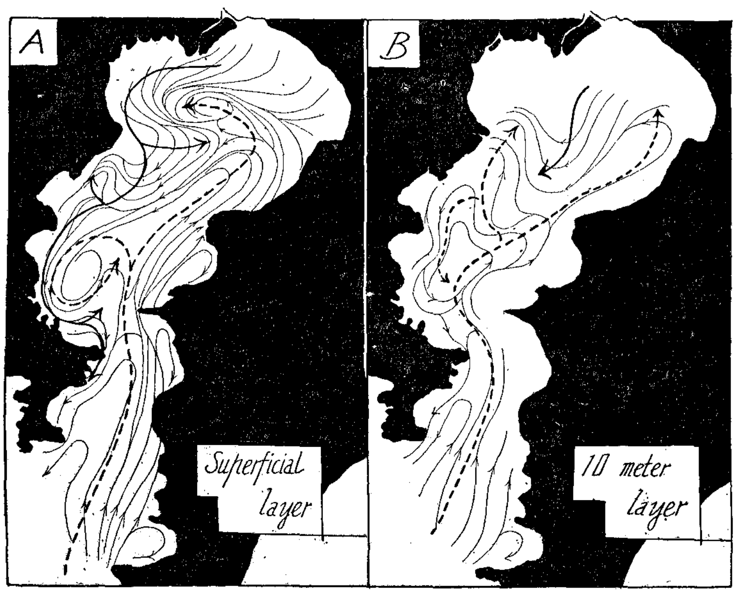

Fig. 4. Stream lines of the circulations of water in Tôkyô Bay determined by the current observations and the distribution of water masses during spring, 1929 (after KOBE MARINE OBSERVATORY, 1931).

———→ inlet water - - - -→ open sea water.

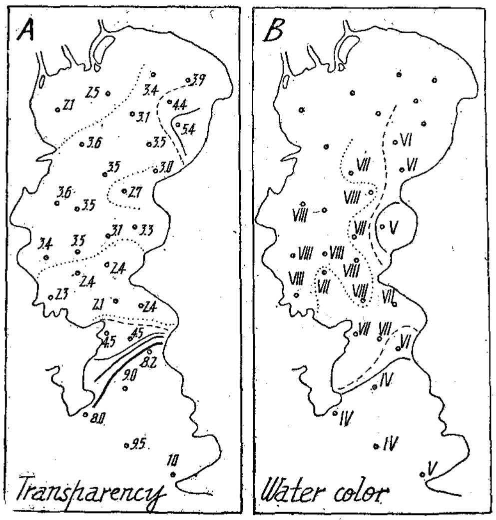

Fig. 5. Distribution of transparency (A) and water color (B) during July 4-9, 1948.

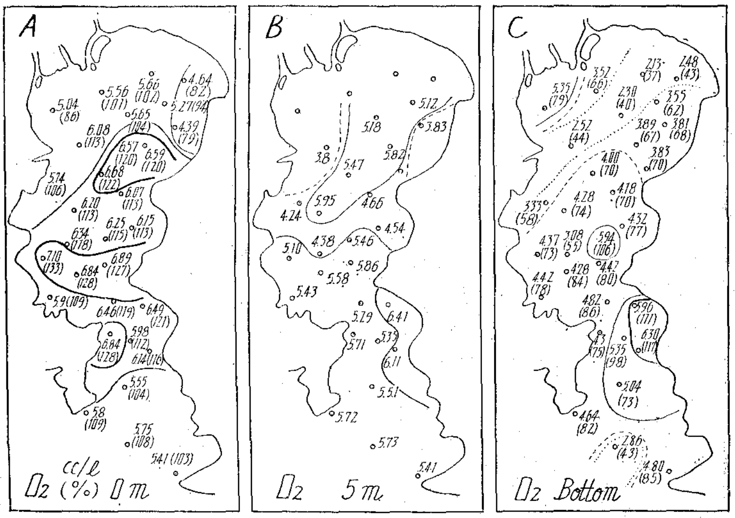

Fig. 6. Distribution of oxygen content (cc/1) and saturation degree (%) (indicated in parentheses) of the superficial layer (A), of the 5 m layer (B) and of the bottom (C).

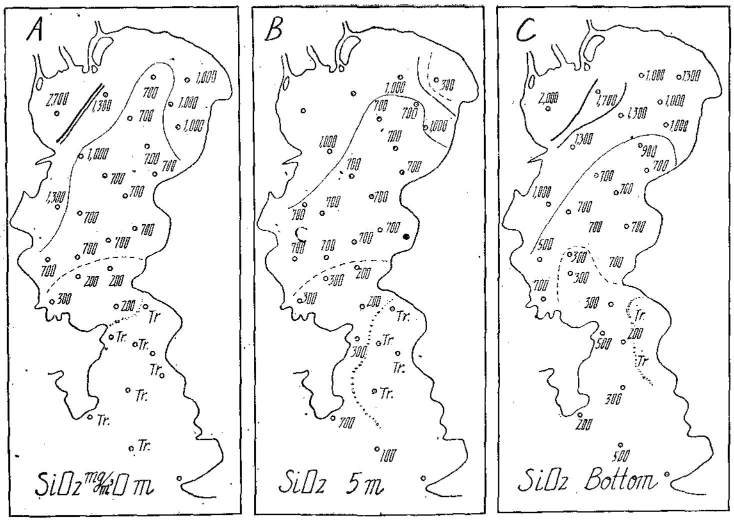

Fig. 7. Distribution of silicates (SiO_2 mg/m^3) of the superficial layer (A), of the 5 m layer (B) and of the bottom (C) during July 4-9, 1948. *Tr.* indicates trace.

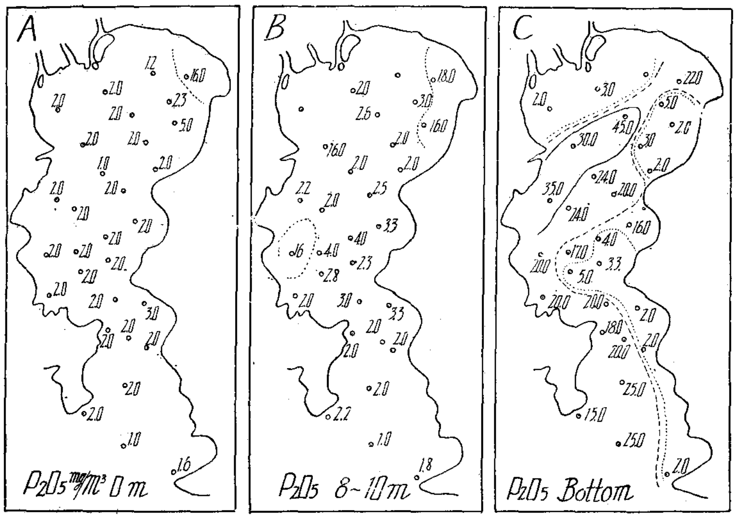

Fig. 8. Distribution of phosphates (P_2O_5 mg/m^3) of the surface layer (A), of the 5 m layer (B) and of the bottom (C) during July 4-9, 1948.

Plankton

A. Quantitative Analysis of Plankton

The settling volume of plankton at the stations in the bay was relatively large, being between 0.1 and 1.0 cc per one meter haul (Fig. 9, A). It was the smallest in the outer region where the volume was less than 0.5 cc. It was also very small in the innermost area, measuring from 0.2 to 0.5 cc per one meter haul. The highest volume was found in the eastern half of the central region, from 0.7 to 1.0 cc.

The same tendency was shown in the case of the total number of plankton. It was also very large throughout the stations, being from 70 to 1,550 thousands per one meter haul (Fig. 9, B). The largest number was about 1,550 thousands near the eastern coast of the central region and two predominant patches of more than 1,000 thousands were found. The smallest was in the innermost area of the inner region and the outer region of the bay, mostly less than 200 thousands. The poor area extended from east to west along the estuaries at the head and further southwards along the western coast.

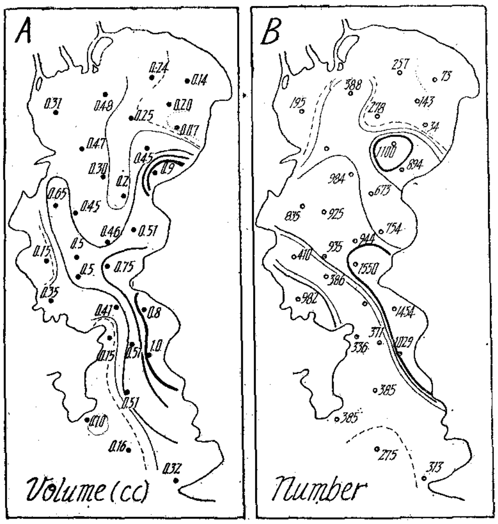

Fig. 9. Settling volume (cc) of plankton per one meter haul from the bottom or 50 meters to the surface (A) and total number of plankton of individuals, cells or colonies per one meter haul. Unit of number is thousand.

There are considerable differences between the inner, central and outer region in both the volume and total number. The settling volume and total number are generally parallel in the inner region, while in the central and outer regions they are not in close accordance to each other (Fig. 10, A). The volume declined at stations where the number was very large, as will be shown later on, because of the richness of diatoms.

As shown in Fig. 11, A, the distribution of zooplankton population was very sporadic in abundance. The quantity was generally very large throughout the stations in the bay. The densest population was found near the eastern coast where two centers showing more than 15 thousands were found. In the innermost region it was

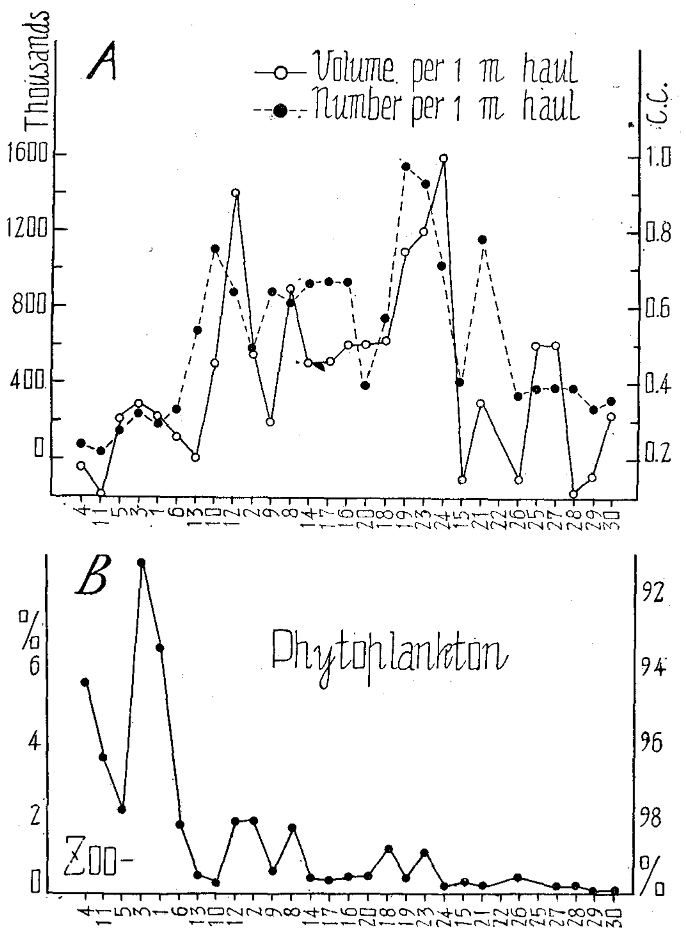

Fig. 10. Relation between settling volume and total number of plankton (A) and percentage composition between zoo- and phytoplankton (B).

also more numerous on the west than on the east. The density of phytoplankton population was almost the same as that of zooplankton population. Both populations were relatively poor near estuaries at the head and in the entrance of the bay. These distributional figures of plankton exhibit a close correlation with the hydrological conditions of the bay, as will be discussed later.

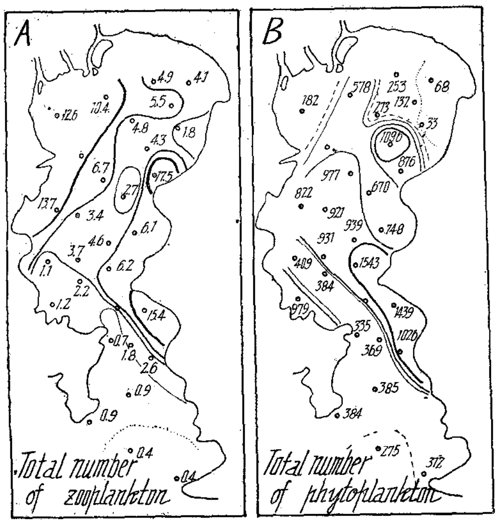

Fig. 11. Distribution of total number of zooplankton (A) and phytoplankton (B).

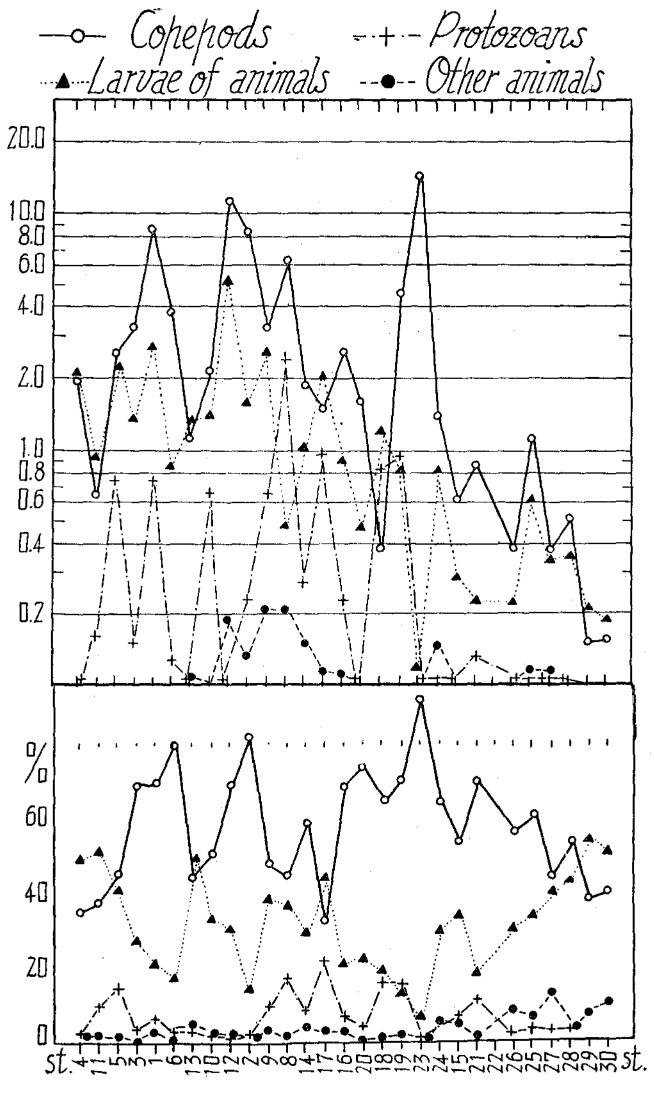

Fig. 12. Number of zooplankton groups at each station (above) and their percentage composition (below).

B. Qualitative Analysis of Plankton

ZOOPLANKTON

Copepods (40–80%), larval forms (10–50%) and protozoans (1–20%) were the important groups in the zooplankton collected in the bay. The other animals are low in percentage composition, less than 10% (Figs. 12 & 13). The number and percentage of copepods in total plankton were higher in the innermost and eastern areas of the central region, except at several stations off Tiba than in the western area of the central region. The highest percentage was obtained at the innermost station (Sts. 1 and 2) and off Huttu (St. 23) in the central region, measuring 80–90% of the total zooplankton. Figs. 14, 15 and 16 show the number and its percentage composition of important species of copepods at each station. Among them *Acartia clausi* was less than 40% of the total copepods, *Oithona nana* 30–60%, *Paracalanus parvus* 1–20%, *Microsetella norvegica* 2–6% and *Oithona similis* less than 30%.

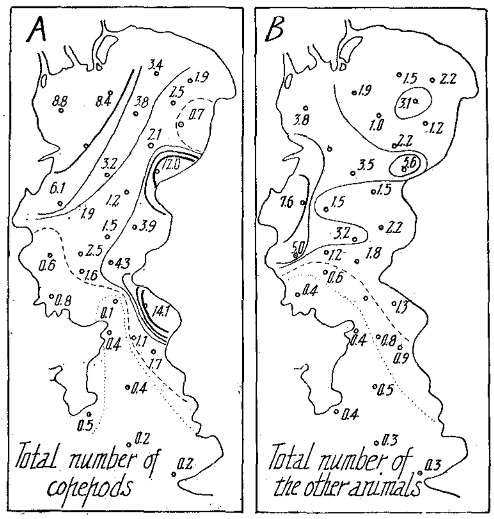

Fig. 13. Distribution of total number of copepods (A) and total number of the other animals (B).

These figures clearly indicate the centers of abundance to be very different between the species. *Acartia clausi* (Fig. 14, A) was the most abundant in the innermost area near the estuary of Edo-gawa (1,000–2,000 individuals per one meter haul; 30–40%) and steadily decreased towards the entrance of the bay (500–800 individuals; 5–20%). It was very sparsely found in the western half of the central region and in the outer region (less than 50; 3%). *A. spinicauda* was not found at all in this survey. *Oithona nana* (Fig. 14, B) was widely distributed and abundantly occurred in the northwestern corner of the inner region and on the eastern coast of the central region (500–8,000: 85–95% and 300–10,000; 40–95%, respectively). Its population decreased from the east to the west in the central region and then towards the mouth along the western coast. *Paracalanus parvus* (Fig. 14, C) was smaller in percentage and number of individuals than the former two species. Although it was evenly distributed in the bay, the main area was the eastern half of Uraga-suido and the

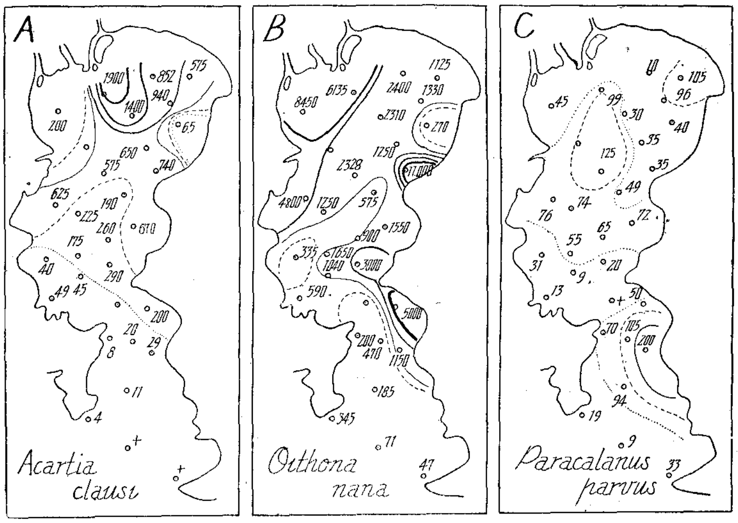

Fig. 14. Distribution of important copepods per one meter haul.

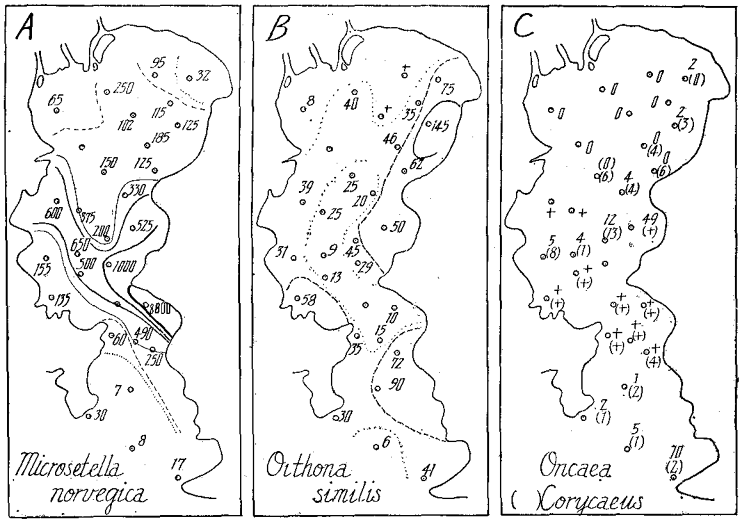

Fig. 15. Distribution of important copepods per one meter haul.

northeastern corner of the inner region off Tiba. *Microsetella norvegica* (Fig. 15, A) also showed a similar distribution to that of *Paracalanus parvus* and *Oithona nana*, but the stock was smaller than the *Oithona nana* population (20–60%; 1,000–8,000).

It decreased towards the inner region where was predominated by *Oithona* and *Acartia*; the appearance of large number of this species is very remarkable. *Oithona similis* (Fig. 15, B) was distributed widely in the bay in small numbers as was *Paracalanus parvus*, and the main dominant area was the outer region. Its percentage reached 10–25% in the mouth and less than 2% in the inner region. In the northeastern corner

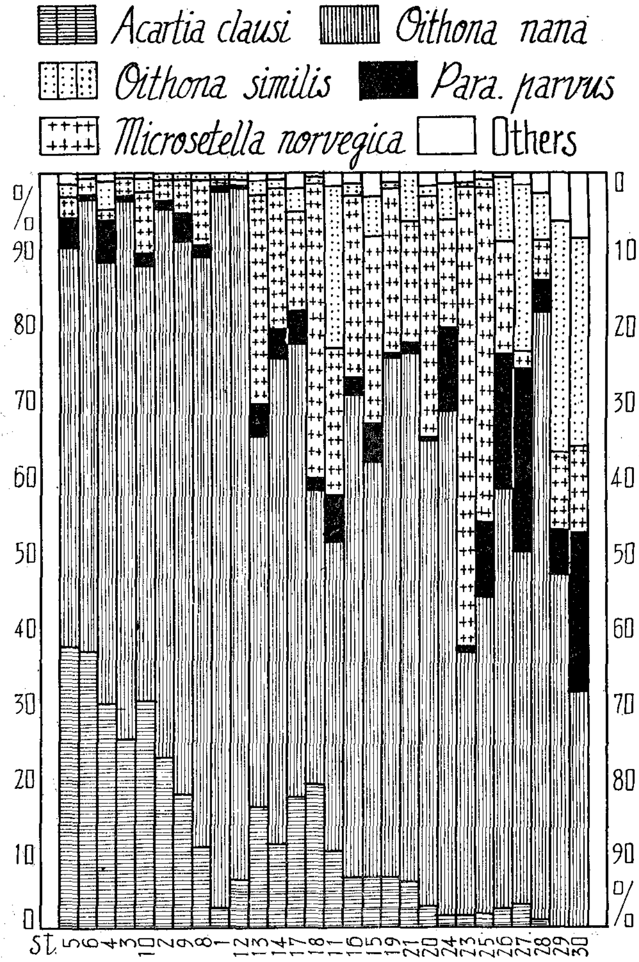

Fig. 16. Percentage composition of important copepods per one meter haul.

of the inner region a narrow patch with relatively large numbers was found, but it may be due to the inflow of more populated water masses of the outer region, judging from the distribution of other open sea forms. *Oncaea media*, *Oncaea venusta*, *Oncaea* spp. and *Corycaeus* spp. were more important in the outer region than in the inner. They occurred mainly in the mouth and along the eastern coast, but were not obtained at all along the western coast and the innermost region. At the stations of the central and outer regions, oceanic copepods, such as *Calanus helgolandicus*, *Cal. tenuicornis*, *Cal. minor* and *Oithona plumifera* were occasionally found.

An inlet form of the tunicate *Oikopleura dioica* (Fg. 17, A) showed also a similar distribution as that of *Oithona nana.* Its distributional center was found at the north-western corner of the inner region off Tôkyô Harbour. It was markedly poor in the outer region. *Oikopleura longicauda* (Fig. 17, A) and *Doliolum* sp. were distributed sparsely in the outer region and extended inwards along the eastern coast. Cladocerans *Evadne tergestina* and *Penilia schmackeri* were sparsely found everywhere. Several species of chaetognaths were found throughout the stations, but among them the inlet forms were abundant in the inner region.

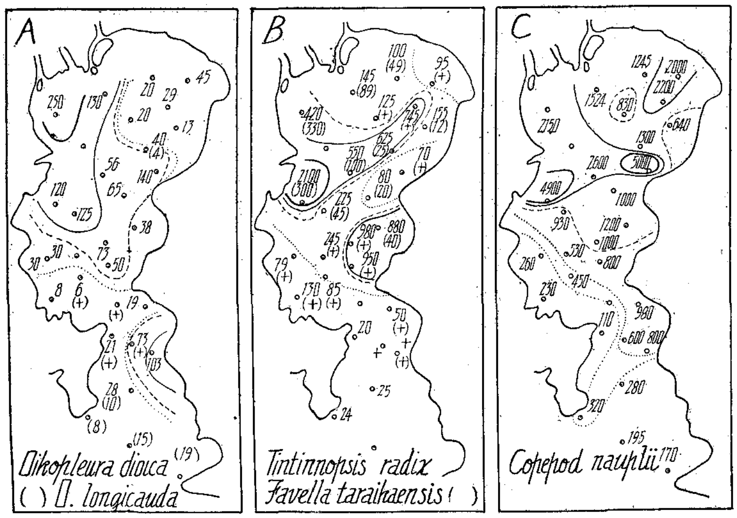

Fig. 17. Distribution of important zooplankton species or groups per one meter haul.

Among protozoans, *Tintinnopsis radix* (Fig. 17, B) was the most abundant and distributed mostly in the inner and central regions where it showed less than 2,000 individuals and decreased eastwards and southwards. Off Huttu there was found also a similar distribution, though less than 400 individuals. Its smallest populations occurred in the outer region and in the northeastern corner of the inner region. *Tintinnopsis mortenseni* occurred sparsely in the central and the outer regions.

Copepod nauplii, comprising mainly of *Oithona nana* and of small number of other forms, were widely distributed and occupied by the high percentage of the total zooplankton. Their maximum numbers were found in the inner region (1,000–5,000). From the mouth to the western half of the central region they were very scarce (1,000–3,000 individuals). Polychaete larvae and pelecypod veligers were widely distributed, though they were dominant larval forms in the central region (less than

130 and 400 respectively). Gastropod veligers, ascidian tadpols and echinoplutei were distributed towards the eastern coast of the central region, though in lesser numbers.

PHYTOPLANKTON

The distribution of some important groups and species of phytoplankton are shown in Figs. 18, 19 and 20. Of diatom groups, Pennatae was the most predomi-

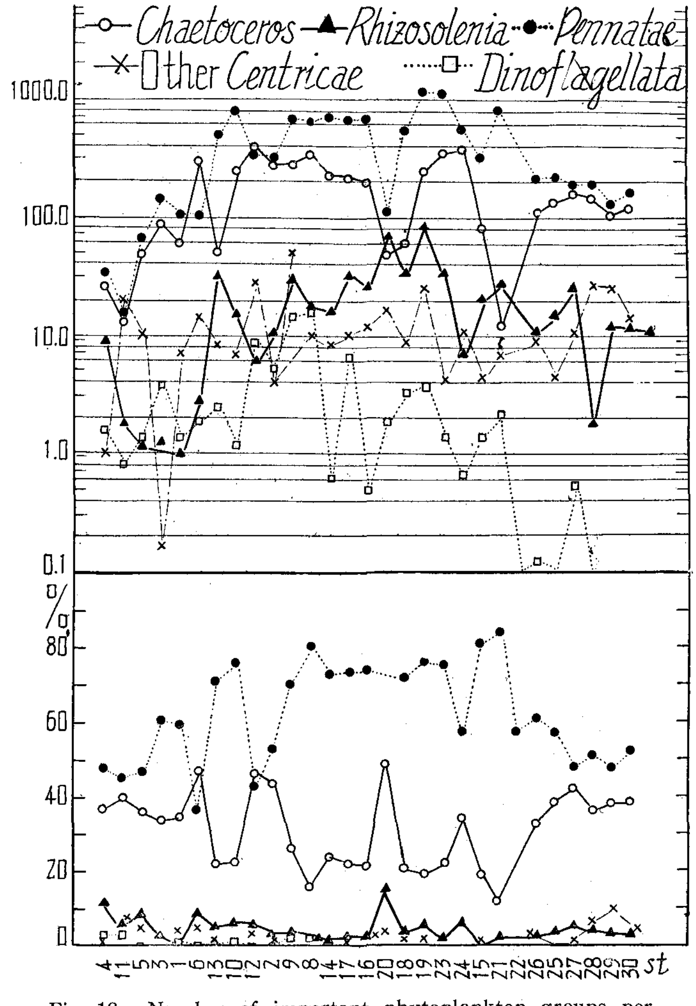

Fig. 18. Number of important phytoplankton groups per one meter haul (A) and their percentage composition (B). Unit of number is thousand.

nant group represented by 85% of total phytoplankton, and less than 1,000 thousands. They occurred abundantly in the central region and decreased towards both the inner and outer regions. *Chaetoceros* comprising many species were represented from 20 to 300 thousands and from 20 to 50%. Its distribution was the same as that of the Pennales group. Other Centricae and Dinoflagellata were very sparse in number and percentage composition.

The main species of Pennales were *Thalassiothrix Frauenfeldii*, *Thalassionema nitzschioides*, *Nitzschia seriata*, *Nitzschia longissima* and *N. sigma*. *Th. Frauenfeldii* (Fig. 20, A) was predominant in the central region and smallest in the northeastern

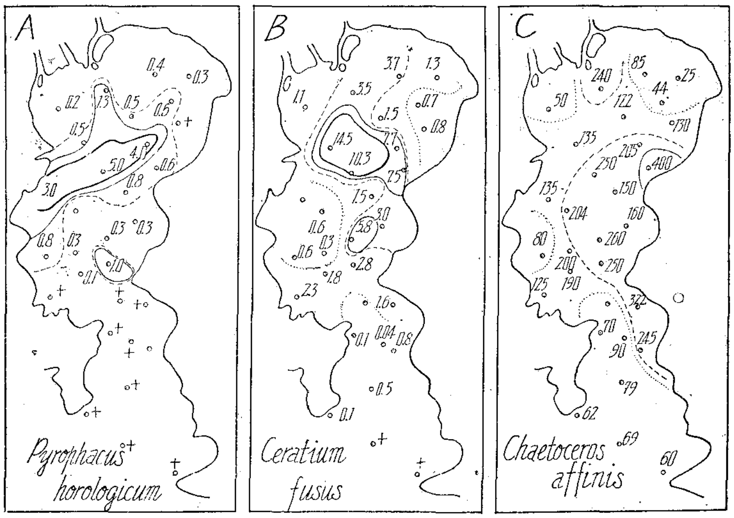

Fig. 19. Distribution of important species of phytoplankton per one meter haul. Unit of number is thousand.

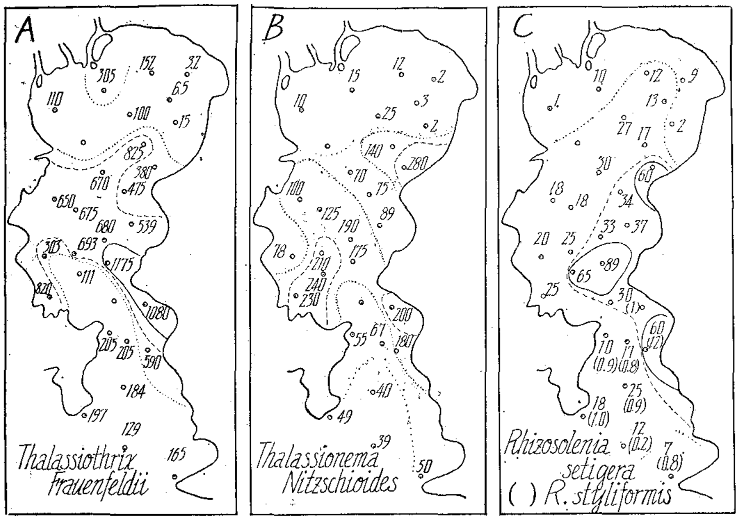

Fig. 20. Distribution of important species of phytoplankton per one meter haul. Unit of number is thousand.

corner of the inner region. *Th. nitzschioides* (Fig. 20, B) was also distributed in the same tendency, but the population was far smaller than that of *Thalassiothrix.* These populations may have been brought by the inflow of oceanic water. The other three species were very poor in number. Of *Chaetoceros, Ch. affinis* was the richest in the eastern part of the central region and decreased towards the entrance and the inner region. The other *Chaetoceros* were unimportant in the inner region but they were relatively abundant. They are *Ch. didymus, Ch. decipiens, Ch. Van Heurcki, Ch. curvisetus, Ch. compressus, Ch. Lorenzianus, Ch. messanensis, Ch. coarctatus,* etc. *Rizosolenia setigera* showed almost the same distribution as in *Ch. affinis. Rhizosolenia styliformis, Rh. calar avis, Rh. Stolterfothii* and *Rh. robusta* occurred in the outer region in small numbers. The Centricae such as *Skeletonema costatum, Guinardia flaccida, Biddulphia sinensis, Bidd. longicruris, Ditylum sol, Eucampia Zoodiacus, Coscinodiscus gigas, Cos. Granii, Cos. centralis,* etc.

Among dinoflagellates *Ceratium fusus* and *Pyrophacus horologicum* (Fig. 19, A, B) were relatively abundant. The former was the richest in the central area of the inner region and spread southwestwards. The latter was also found very abundantly off Yokohama and spread eastwards. The other dinoflagellates occurred at the central and mouth of the bay in small numbers. They are *Peridinium depressum, Per. conicum, Cer. furca, Cer. pennatum, Cer. macroceros, Cer. masciliense, Cer. tripos, Cer. trichoceros* and *Cer. molle.*

The difference in the distribution of plankton organisms indicate the influence of the hydrological and topographical conditions. The discharge from the rivers and polluted waters in the northern and western coasts of the bay as well as both the inflow and outflow of water and the circular currents seem to control the distribution of plankton. This may be explained by a comparison between the plankton communities of different regions. The populations of *Pyrophacus horologicum* and *Ceratium fusus* occurred most abundantly in the inner area northeast of Yokohama. This indicates that the two species can thrive in highly polluted and less-saline water. The diatoms occurred abundantly in the central region than in the inner region possessing rather stagnant, highly polluted and lower saline water. The concentration of diatom communities in the surface layer of the central region may suggest the mixture of different water masses which originate from the inner coastal region and from the outer open sea.

Discussion

Regional Distribution of Plankton

From preceding data and figures, the plankton communities of Tôkyô Bay may be represented by the following 5 dominant copepod species, and their mixed communities. Among the predominant copepods, *Oithona nana* occurred widely in large quantities, but the remaining 4, namely *Acartia clausi, Microsetella norvegica, Para-*

calanus parvus and *Oithona similis* are rather restricted in occurrence, so that the regional demarcation may be possible. The following distributional map is thus drawn according to the relative abundance of these associated copepods (Fig. 21, Table 1 and 2 and Plates XIX and XX).

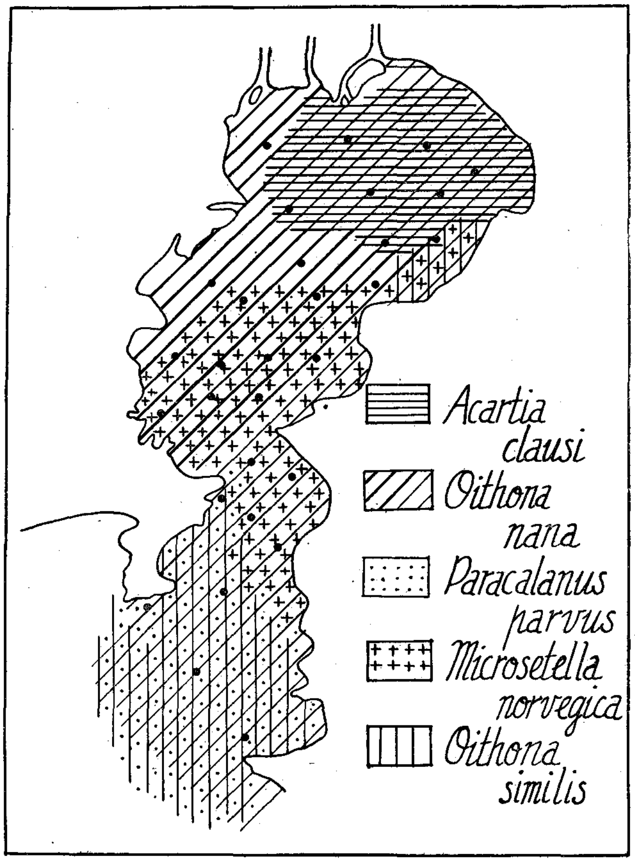

Fig. 21. Distribution of dominant copepods in Tôkyô Bay.

1. *Oithona nana—Acartia clausi* community.

In the northeastern area of the inner region the water is abundantly occupied by *Oithona nana* associated with large numbers of *Acartia clausi*, copepod nauplii and *Ceratium fusus*. Other associates are given in the first column of Table 1. The animal productivity, especially of copepods, is large, but the vegetative productivity is relatively small in such sheltered waters.

This area close to the estuaries is shallow, and its water is highly stagnant with brown color and very small transparency. The chlorinity and oxygen content are lower than in other communities. The oxygen content of the bottom layer is very small and low in percentage.

2. *Oithona nana* community.

Along the northwestern coast off Yokohama, other copepods than *Oithona nana* are very few. The largest population and percentage composition of *Oithona nana* are 8,500 and 95% of all copepods respectively. This community is characterized by the predominance of neritic tintinnids *Tintinnopsis radix* and *Favella taraikaensis*, tunicate *Oikopleura dioica*, copepod nauplii, dinoflagellates *Pyrophacus horologicum* and *Ceratium fusus*. These associated species occupied the largest population throughout the stations. *Chaetoceros affinis*, *Thalassiothrix Frauenfeldii*, *Thalassionema nitzschioides*, *Rhizosolenia setigera* and among copepods *Microsetella*, *Oithona similis* and *Paracalanus parvus* are also distributed, but they are not so common as in the other areas. According to FUJIYA (1952), *Skeletonema costatum* is most abundant in July. In my sample, however, it is very small in number, except in the innermost region. The productivity in this area is almost similar to the former community in both the zoo- and phytoplankton.

The area occupied by this community is relatively shallow, approximately 30 m in depth. The salinity, oxygen, phosphates and transparency are the lowest in the bay. The water is brown in color and much polluted by sewage from the city. The silicates are most abundant. These hydrological conditions seem to control the diatom growth and to favour some special species of plankton.

3. *Oithona nana*—*Microsetella norvegica* community.

The central region of the bay is occupied by large numbers of *Oithona nana* and *Microsetella norvegica*. The largest number of both copepods is 8,500 and 8,800 respectively. This community is associated with large numbers of diatoms such as *Ch. affinis*, *Thalassiothrix Frauenfeldii*, *Thalassionema nitzshioides*, *Rhizosolenia setigera*, etc. which are the most predominant in the bay. Among zooplankton associated with this, the copepods *Acartia clausi*, *Paracalanus parvus*, *Oncaea*, *Corycaeus* and a tunicate *Oikopleura dioica* are important, but these populations are smaller than in the other areas. The productivity of both zoo- and phytoplankton is greater in the eastern half than in the western half.

The western half of this area is deeper than the eastern half. The water shows higher transparency, higher chlorinity, larger contents of oxygen, lower silicates and phosphates than in the foregoing two areas.

4. *Oithona nana*—*Paracalanus parvus*—*Oithona similis* Community.

The outer region of the bay, south of Kannon-zaki, is characterized by the mixed high percentage of three or four important copepods, *Oithona nana*, *Oithona similis* and *Paracalanus parvus* (or *Microsetella norvegica* too). Of these, *Oithona nana* and *Microsetella* are far poorer than in the inner region, and many oceanic species such as *Oikopleura longicauda*, *Doliolum*, *Calanus*, *Eucalanus*, *Rhizosolenia* and *Chaetoceros* spp. are found in small numbers. The productivity of both zoo- and phytoplankton is smallest.

TABLE 1. Composition of four major copepod communities in Tôkyô Bay. (Unit of phytoplankton number is thousand and each number per one meter haul from surface to bottom or less than 50 meters)

	Oithona-Acartia community	*Oithona* community	*Oithona-Microsetella* community	*Oithona-Microsetella-Paracalanus-Oith. similis* community
Settling volume of total plankton (cc/one meter of haul)	0.2 — 0.48	0.3 — 0.65	0.2 — 1.0	1.0 — 0.5
Total number of plankton (thousand of one meter of haul)	34 — 1,100	195 — 980	400 — 1,150	300 — 388
Total number of zooplankton	4,100 — 10,500	6,700 — 13,700	1,100 — 15,400	400 — 2,600
Total number of phytoplankton (thousand of one meter of haul)	33 — 1,096	180 — 980	400 — 1,550	300 — 385
Zooplankton				
Acartia clausi	600 — 1,900	200 — 700	20 — 740	< 11
Oithona nana	1,125 — 6,139	1,200 — 8,450	330 — 11,000	47 — 480
Paracalanus parvus	10 — 100	30 — 120	75	9 — 94
Microsetella norvegica	32 — 250	60 — 600	125 — 8,800	7 — 17
Oithona similis	< 75	8 — 40	9 — 62	6 — 41
Oncaea media	< 2	0	< 50	< 10
Corycaeus spp.	< 2	0	< 15	< 2
Copepod nauplii	60 — 2,000	2,100 — 3,000	230 — 5,000	110 — 280
Tintinnopsis radix	90 — 275	400 — 2,100	50 — 1,000	< 25
Favella taraikaensis	< 100	100 — 300	< 100	0
Oikopleura dioica	20 - 130	30 — 250	8 — 140	< 21
Oikopleura longicauda	0	0	< 1	< 19
Phytoplankton				
Pyrophacus horologicum	0.3 — 1.3	0.2 — 3.0	0 — 0.8	a little
Ceratium fusus	0.7 — 14.5	1.1 — 10.3	0.3 — 5.8	0.1
Chaetoceros affinis	25 — 240	50 — 130	80 — 400	60 — 70
Thalassionema nitzschioides	2 — 25	10 — 100	70 — 240	40 — 55
Thalassiothrix Frauenfeldii	15 — 305	100 — 820	111 — 1,175	130 — 200
Rhizosolenia setigera	2 — 27	1 — 30	20 — 89	7 — 25
Rhizosolenia styliformis	0	0	1 — 1.2	0.2 — 0.9

TABLE 2. Hydrological conditions in four major copepod communities in Tôkyô Bay.

	Oithona-Acartia community			*Oithona* community			*Oithona-Microsetella* community			*Oithona-Microsetella-Paracalanus-Oith. similis* community		
Depth (m)	<20			<30			<20 (eastern) 20–60 (western half)			100–700		
Transparency (m)	2.5–4.0			2.1–3.6			2.0–5.0			8–10		
Water color (No.)	Brown			Brown			7-8			4–5		
	0 m	5 m	bottom	0 m	5 m	bottom	0 m	5 m	bottom	0 m	5 m	bottom
Temperature (°C)	18–20	—	16.5–21	20–22	—	16–19	21–23	—	15.8–17	20–21.8	—	7-17.0
Chlorinity (‰)	16–18.1	—	17.5–18.5	10–15.7	—	15–17.5	15–17.5	17.5–18	17.5–18.8	17.7–18.3	18.4–18.6	18.8–19.0
Oxygen (cc/l)	4.6–6.08	5.1-5.2	2.1–3.8	5–6.6	3.8–5.5	4.0–5.3	6.1–7.1	5.0–6.0	4.1–6.5	5.4–6.8	5.4-5.7	4.3–5.0
" (%)	82–113	—	37–67	86–122	—	70–79	113–133	—	70–117	103–128	—	73–75
SiO_2 (mg/m^3)	700–1,000	300–700	100–1,700	700–2,700	—	700–2,000	<700	<700	300–700	Tr	100–300	300–500
P_2O_5 (mg/m^3)	2	2–5	3–5	2	2	2-3.5	2–3	3–5	5–20	1-2	1-3	3-25

As Tôkyô Bay is a secondary inlet extended from Sagami Bay, the plankton community near the mouth shows a more embaymental characteristics than in the bays of Kamaisi (YAMAZI, 1954) and Miyako (YAMAZI, 1954) where are strongly influenced by the open sea water. Diatoms and zooplankton peculiar to inlet waters occur very abundantly in the inner region north of Kannon-zaki.

Current System as Inferred from Plankton Distribution

The plankton is generally at the mercy of the hydrological factors especially horizontally, since it must move with the water. The variation in the distributional area of the abundance of the plankton and of the number of species suggests the movement of the water masses. The use of plankton as indicators of the coastal water movements has been discussed by many workers (SØMME, 1933, 1934; REDFIELD and BEALE, 1940; REDFIELD, 1941; RUSSELL, 1935; 1936; FRASER, 1952; WIBORG, 1954). A preceding paper dealing with the plankton of Miyazu Bay (YAMAZI, 1955) showed that the inlet plankton community which are distributed regionally can be used as indicators of water masses and their circulation in the bay or inlet. We may consequently examine the nature of the water circulation of the bay or inlet to see if it can account for the fluctuations in number of species and population density in different places, and to learn to what extent the regional plankton community may be carried into and out the bay or inlet by water movement, although a pronounced diurnal or vertical migration needs to be fully discussed.

The inlet or bay waters surrounding Japan in Kurosio region are characterized by the predominance of the following species: *Acartia clausi* (from winter to summer), *Acartia spinicauda* (from summer to autumn), *Oithona nana, Favella taraikaensis, Tintinnopsis radix, Sagitta delicata, Sagitta crassa* (in winter), *Sagitta crassa* f. *naikaiensis* (in summer and autumn), *Oikopleura dioica* and a diatom *Skeletonema costatum.* These species can be used as indicators of inlet or estuarine waters. In Tôkyô Bay *Acartia clausi, Oithona nana, Oikopleura dioica, Sagitta crassa* f. *naikaiensis, Skeletonema costatum* spread along the western coast from the innermost area and extend further out of the bay in small numbers. A part extends eastwards off Haneda and Yokohama where *Acartia* occurs abundantly. In the northeastern corner upwelling of underwater runs westwards, and then mixes with *Acartia*-water near estuaries.

Microsetella community which dominates the central region of the bay extends from the eastern area of the inner region towards the north and southwards along the eastern coast. The small specimens of this copepods occur widely in the whole area, but are very scanty in the outer region southwards from Kannon-zaki where the inflowing current is strong. The water of this area contains abundant diatoms such as *Thalassiothrix Frauenfeldii, Thalassionema nitzschioides* and *Nitzschia seriata,* and copepods such as *Oithona similis* and *Oncaea* spp. *Chaetoceros* spp. are also important.

The above fact seems to indicate that the inner region of the bay is clearly demarcated from the outer region topographically, but the plankton communities of the inner region consist of a mixture of inner and outer origins.

The water of the outer region is characterized by the predominance of offshore

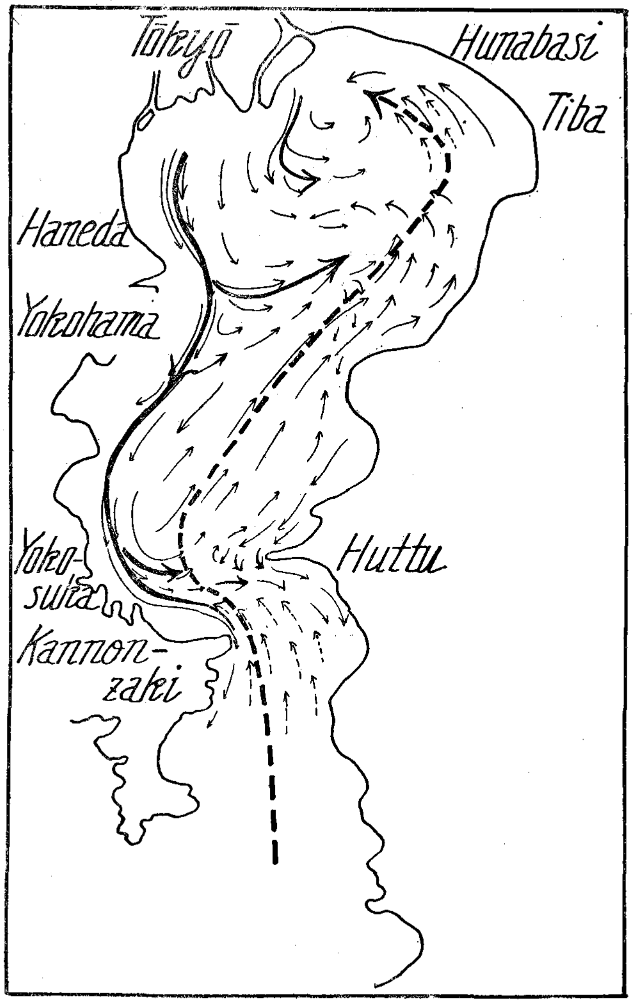

Fig. 22. Current system in Tôkyô Bay deduced from the distribution of plankton communities.
-----→ In-coming open sea water, ——→ Circulating, partly out-going inlet water.

forms comprising *Oikopleura longicauda*, *Fritillaria haplostoma*, *Oncaea*, *Corycaeus*, several calanoids, oceanic diatoms and dinoflagellates. They are practically abundant out of the bay. They extend to the eastern area of the inner region, and a small patch is found in the central area where they are associated with the inlet forms.

The populations of these immigrants of offshore origin are very small in number and wholly absent in the northwest corner of the inner region.

The water masses as indicated by the distribution of plankton communities are in good agreement with the general features of the circulation observed by drift-bottle method and current measurements in the surface or 10 m layers (KOBE MARINE OBSERVATORY, 1931). Summarizing the results of plankton investigations stated above, I give here a synthetic current chart of Tôkyô Bay, though in-coming open sea water be could noted treat minutely as shown in Fig. 22. Especially the complex nature of the water movements off Yokosuka to Huttu-saki and off Haneda and Yokohama can be understood from the components of plankton communities there. It will be necessary to treat the life history and the age length on each species definitely in future. A distributional study of the size frequency in growth stages of these inlet copepods will also give us many informations in regard to the origin of the stock and supply our present knowledge on the water masses and their movements.

Summary

1. The regional quantitative distribution of plankton in Tôkyô Bay during the summer of 1948 is discussed.

2. The bay is characterized by the predominance of copepod *Oithona nana* throughout the area. In percentage composition of the total copepods, however, three faciations, all accompanied by *Oithona nana*, are recognized, that is (1) *Oithona nana* and *Acartia clausi* community, associated with *Oikopleura dioica*, *Sagitta crassa* f. *naikaiensis* and *Skeletonema costatum* in the innermost region, (2) *Microsetella norvegica* and *Oithona nana* community in the central region, (3) *Paracalanus parvus*, *Oithona nana* and *Oithona similis* community, associated with *Corycaeus* spp, *Oncaea* spp. and calanoids in the entrance or outer region.

3. The ecological conditions of zoo- and phytoplankton are discussed on the basis of the previous hydrological data.

4. The variation in the center of abundance of plankton communities is closely correlated with the surface circulation, deduced from the hydrological observations. The water movement of this bay is thus clearly interpreted from the regional distribution of plankton community.

5. It is shown that the planktonic indicators for inlet or bay waters are *Acartia clausi* (from winter to early summer), *Oithona nana, Acartia spinicauda* (from summer to autumn), *Microsetella norvegica, Oikopleura dioica, Sagitta crassa* f. *naikaiensis* (from summer to autumn), *Sagitta crassa* (from winter to spring), *Saggita delicata, Tintinnopsis radix, Favella taraikaensis*, diatoms *Skeletonema costatum, Thalassionema, Thalassiothrix* and *Nitzschia*. *Oithona similis, Oncaea media, Oncaea venusta, Corycaeus*, calanoid copepods, *Oikopleura longicauda, Fritillaria* spp., *Sagitta enflata*, doliolids, etc. are regarded as indicators of open sea water or outer region of bay.

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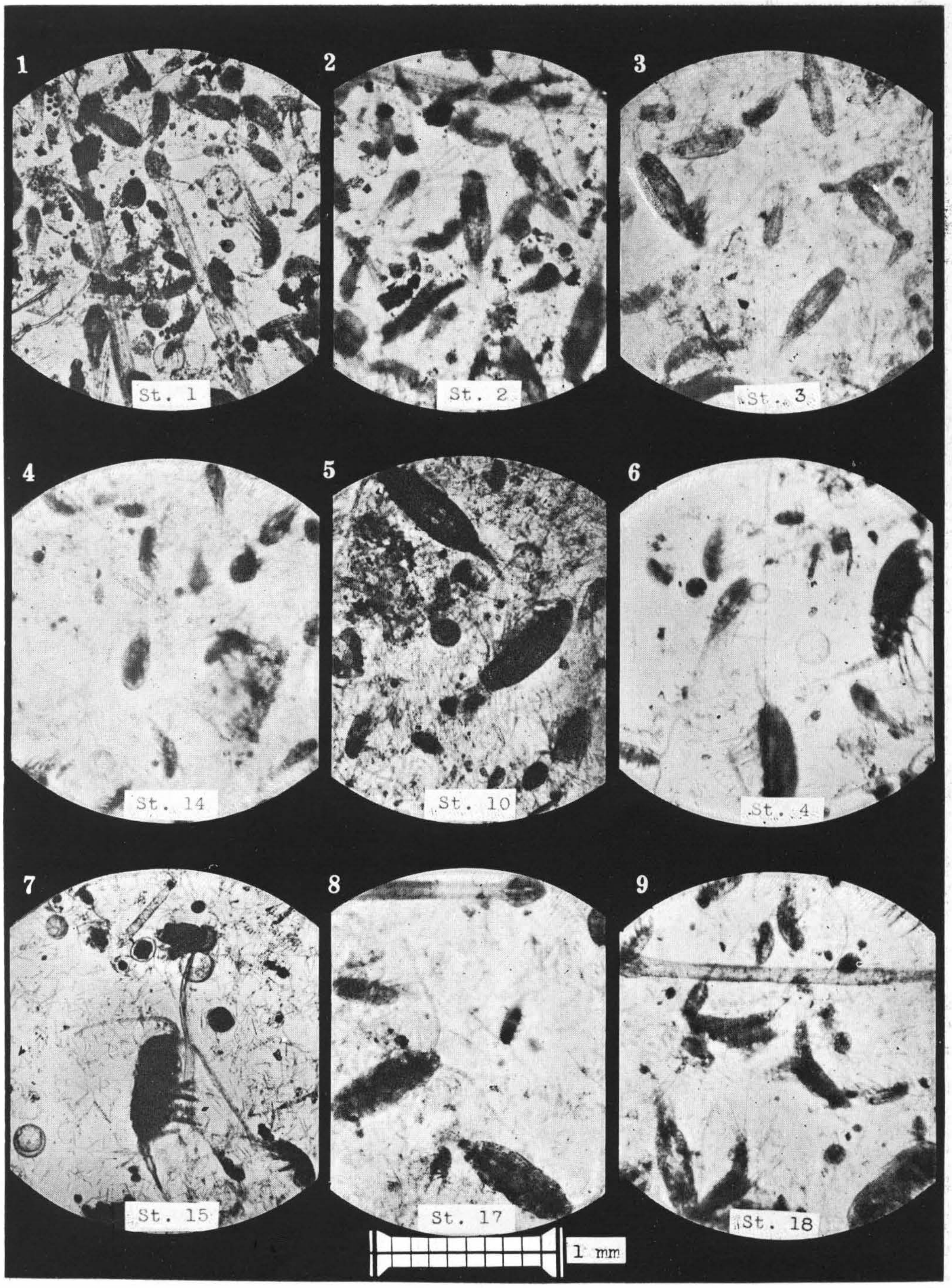
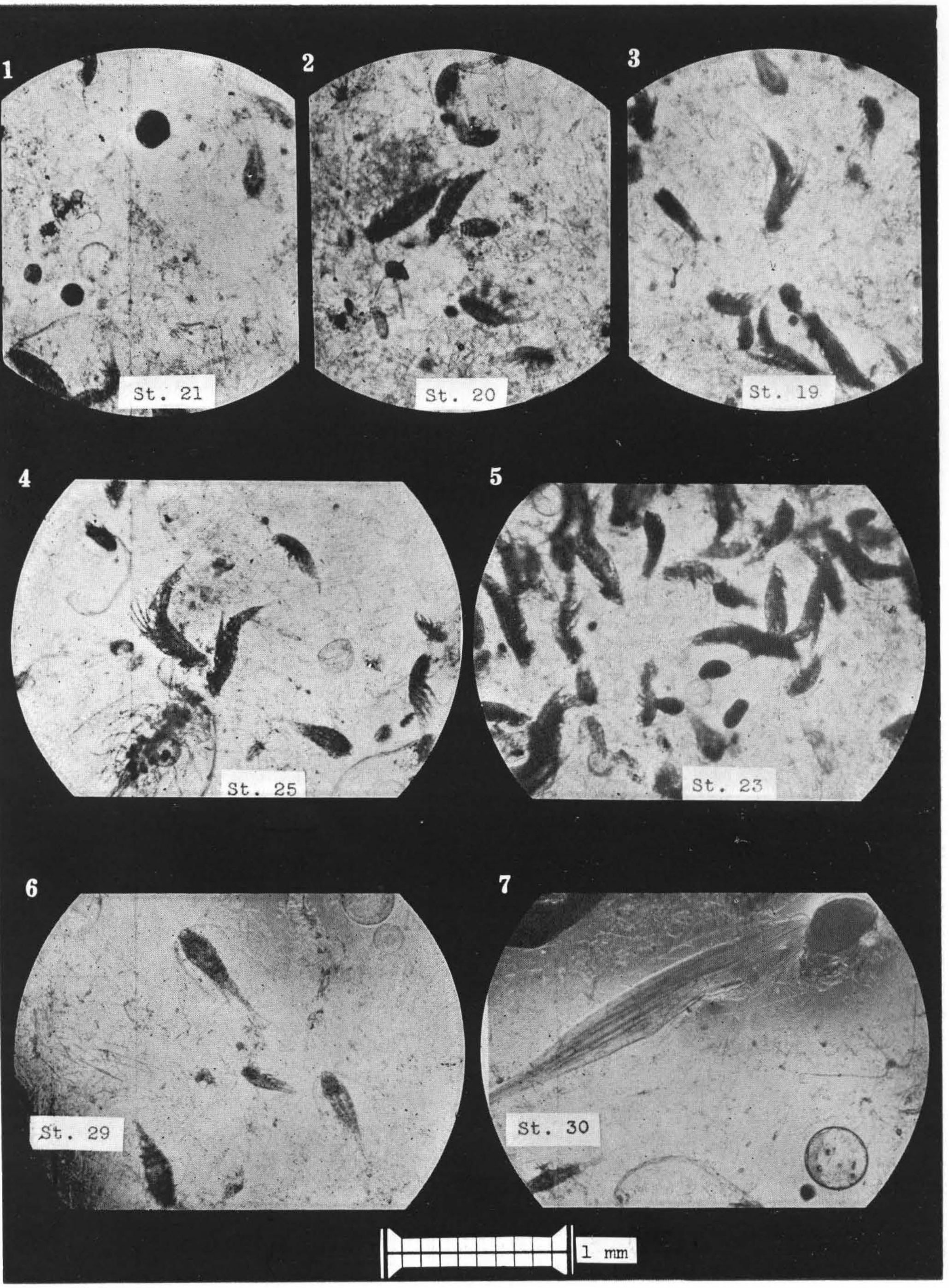


I. YAMAZI: PLANKTON INVESTIGATION IN INLET WATERS, XVI.



I. YAMAZI: PLANKTON INVESTIGATION IN INLET WATERS, XVI.

EXPLANATION OF PLATES XIX-XX

PLATE XIX

Fig. 1. *Oithona nana* community, associated with *Sagitta crassa* f. *naikaiensis*, and pelecypod veliger (Station 1).

Fig. 2. *Oithona nana–Acartia clausi* community associated with the same species of figure 1 (Station 2).

Fig. 3. The same community, associated with copepod nauplii, *Microsetella norvegica* and diatoms (Station 3).

Fig. 4. *Oithona nana* community, associated with copepod nauplii, *Tintinnopsis radix* and diatoms (Station 14).

Fig. 5. *Oithona nana—Acartia clausi* community, associated with copepod nauplii, pelecypod veliger, *Tintinnopsis radix* and diatoms (Station 10).

Fig. 6. The same community, associated with copepod nauplii, *Oithona similis*, pelecypod veliger and diatoms (Station 4).

Fig. 7. *Oithona nana—Microsetella norvegica* community, associated with *Oikopleura dioica*, *Tintinnopsis radix* and diatoms (Station 15).

Fig. 8. *Oithona nana—Microsetella norvegica* community, associated with *Paracalanus parvus*, *Sagitta crassa* f. *naikaiensis* and diatoms (Station 17).

Fig. 9. The same community, associated with *Acartia clausi*, *Paracalanus parvus*, pelecypod veliger, *Sagitta crassa* f. *naikaiensis*, *Tintinnopsis radix* and diatoms (Station 18).

PLATE XX

Fig. 1. *Oithona nana—Microsetella norvegica* community, associated with pelecypod veliger, copepod nauplii and diatoms (Station 21).

Fig. 2. The same community, associated with copepod nauplii, *Peridinium* and diatoms (Station 20).

Fig. 3. The same community, associated with diatoms (Station 19).

Fig. 4. The same community, associated with *Penilia schmackeri*, *Oikopleura dioica*, copepod nauplii and diatoms (Station 25).

Fig. 5. *Microsetella norvegica—Oithona nana* community, associated with pelecypod veliger, copepod nauplii and diatoms (Station 23).

Fig. 6. *Oithona nana—Paracalanus parvus—Oithona similis* community, associated with copepod nauplii and *Coscinodiscus* (Station 29).

Fig. 7. The same community, associated with *Oikopleura longicauda*, *Oikopleura dioica*, *Coscinodiscus* and diatoms (Station 30).