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Citation	PUBLICATIONS OF THE SETO MARINE BIOLOGICAL LABORATORY (1953), 3(1): 75-108
Issue Date	1953-07-30
URL	http://hdl.handle.net/2433/174458
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

Kyoto University

PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

VII. THE PLANKTON COLLECTED DURING THE CRUISES TO THE NEW YAMATO BANK IN THE JAPAN SEA*

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With 19 Text-figures

Introduction

During April, July and September of 1950, oceanographical surveys of the New Yamato Bank, a small fishing area lying northeast of Oki Bank, were carried out by the R. M. S. "Kurosio-Maru" of the Maizuru Marine Observatory under the leadership of Dr. Y. TOYOHARA, of the Institute of Geophysics of Kyoto University. During her cruises made in April and September, the writer himself had an opportunity to join the party to cooperate in the oceanographical works, and thus collected plankton samples at every station. Of these samples the pelagic tunicates and chaetognaths only have been taxonomically studied by Dr. TOKIOKA and a paper has already been published (TOKIOKA, 1951). The present paper deals with all these plankton samples, both quantitatively and qualitatively, in relation to the hydrological factors, which influence their habitat and distribution, and in connection here with the stability of the water masses indicated by the populations of some leading plankton animals.

The writer wishes to express his sincere thanks to Dr. Y. TOYOHARA and the officers on board of the Maizuru Marine Observatory for making this survey possible most effectively. Special thanks are due to Messrs. A. NAKAMURA, H. MAÉDA and S. FUSE of Kyoto University on board the ship for their help and courtesies in collecting the material. Further he desires to thank Prof. D. MIYADI, Dr. T. TOKIOKA, and in particular Dr. H. UTIMOMI who read the manuscript for their kind guidance and encouragement.

* Contributions from the Seto Marine Biological Laboratory, No. 203.

Collection and Analysis of Samples

Samples of plankton and hydrological data for the present study were obtained from the R. M. S. " Kurosio-maru ", during three cruises from the Maizuru Bay to the New Yamato Bank, 70 miles off the cape Kyôga-saki (Fig. 1). The location of stations is shown in the key map (Fig. 2). At every station the surface plankton samples were hauled by means of TAMURA's cruise plankton collector (TAMURA, 1949) while sailing at a speed of 6 knots for periods of 3 to 10 minutes. This plankton collector, which is 2 cm and 8 cm in diameter of the mouth and largest part respectively and about 40 cm in length, is equipped

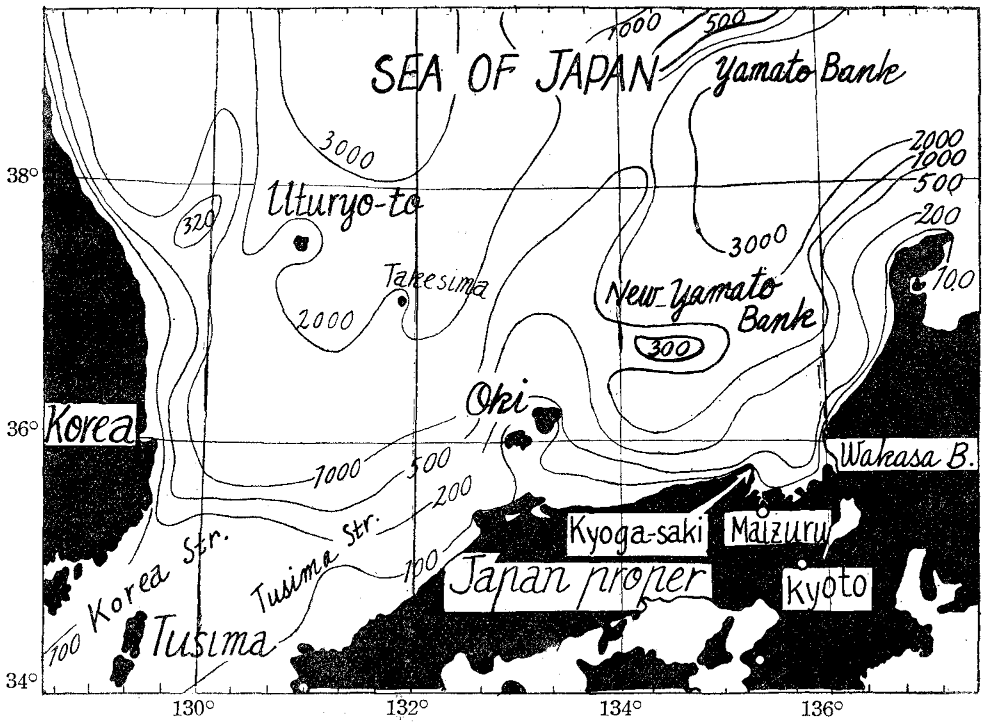

Fig. 1. Map of the southern Japan Sea showing the bathymetric contours and the position of stations referred to in the text.

with No. XX-13 MÜLLER's gauze. At some representative stations in each cruise (8 stations in the 1st cruise, 11 in the 2nd cruise and 6 in the 3rd cruise), plankton samples were vertically collected at about 50 m intervals from every layer (ranging between 50–350 m) to the surface with a KITAHARA's quantitative silk tow-net; this instrument shows ca. 22.5 cm in the mouth diameter and ca. 1 m

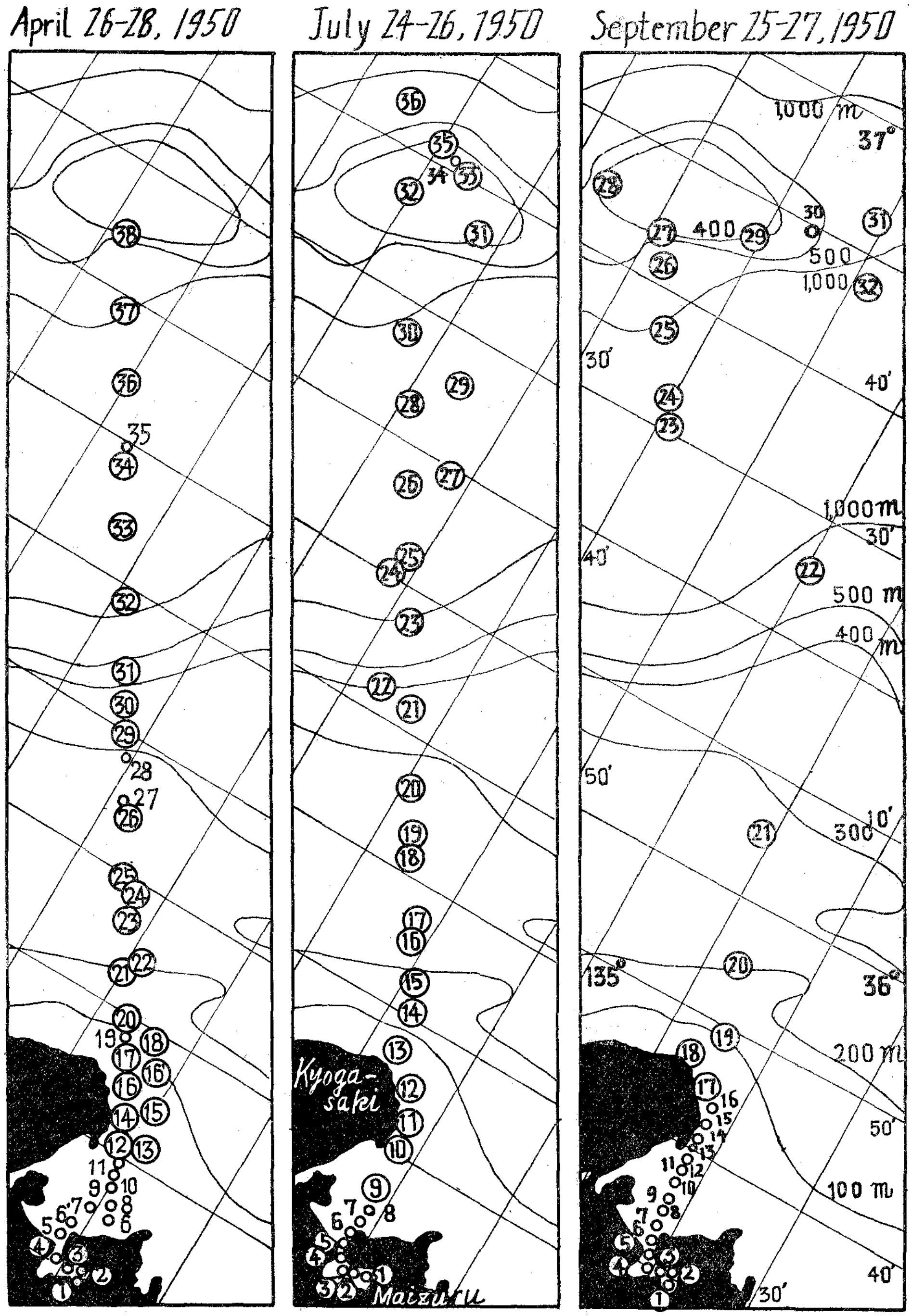

Fig. 2. The location of stations during three cruises to New Yamato Bank from Maizuru, in 1950.

long, and stretched with No. XX-13 MÜLLER's gauze. During the 2nd cruise in July, however, sampling with a closing net was also employed. The number of these stations with the hydrological data obtained is indicated in Figs. 3 & 4.

Standard hydrological observations for temperature, chlorinity, phosphates (P_2O_5), silicates (SiO_2), oxygen contents and catalytic activity of sea water were made vertically at these representative stations. SECCHI's disc measurements of transparancy, FOREL's scale measurements of water color and pH of sea water were carried out during daylight stations. The methods herewith used for the determination of the catalytic activity of seawater, which is expressed by the reaction velocity of decomposing hydrogen peroxide, have been amply described (MATSUDAIRA, 1950, 1951), and for that reason will not be repeated here. In dealing with the populations of plankton, the large-sized animals, such as chaetognaths, tunicates and hydromedusae were separated from the remaining smaller forms in the laboratory. For each station the total number and settling volume of zoo- and phytoplankton, either or both, were calculated in each of samples per 10 minutes haul horizontally and per 10 meters haul vertically. The rough volume of every sample was measured with a measuring cylinder by settling method with 24 hours (YAMAZI, 1950).

Hydrological Conditions

1. First Cruise (April 26-28, 1950)

The hydrological condition along the line of stations observed during the first cruise from Maizuru Bay to the New Yamato Bank made in spring are shown in Figs. 3 and 4. The chlorinity from the surface to the 100–150 m layer was between 18.8 Cl ‰, (33.96 S ‰) and 19.1 ‰ (34.5 S ‰) and the temperature was between 6°C and 13°C. In the deeper water layer lower than about 150 m, the chlorinity was lower than in the upper layer, namely between 18.87 ‰ (34.09 S ‰) and 18.9 ‰ (34.1 S ‰), and the temperature between 6°C and 15°C. The coastal water extended superficially as far 5 miles off the coast (Kyôga-saki). We found the typical Tusima Current water with a chlorinity above 19.1 Cl ‰ (34.5 S ‰) and a temperature above 12°C flowing eastwards between the surface and the 100–150 m layer. The isotherm of 12°C was seen below the 50 m layer at St. 8 and St. 30, while on the 150 m layer at St. 20, 25 and 35 (Fig. 3 A). In Maizuru Bay, higher temperature (14°C) and lower chlorinity (16.58 Cl ‰ (29.95 S ‰)) was observed at the surface, while 13°C and 18.5 Cl ‰ (33.6 S ‰) at the 10 m bottom layer (Fig. 3, A–B). Within the bay, the contents of silicates in the

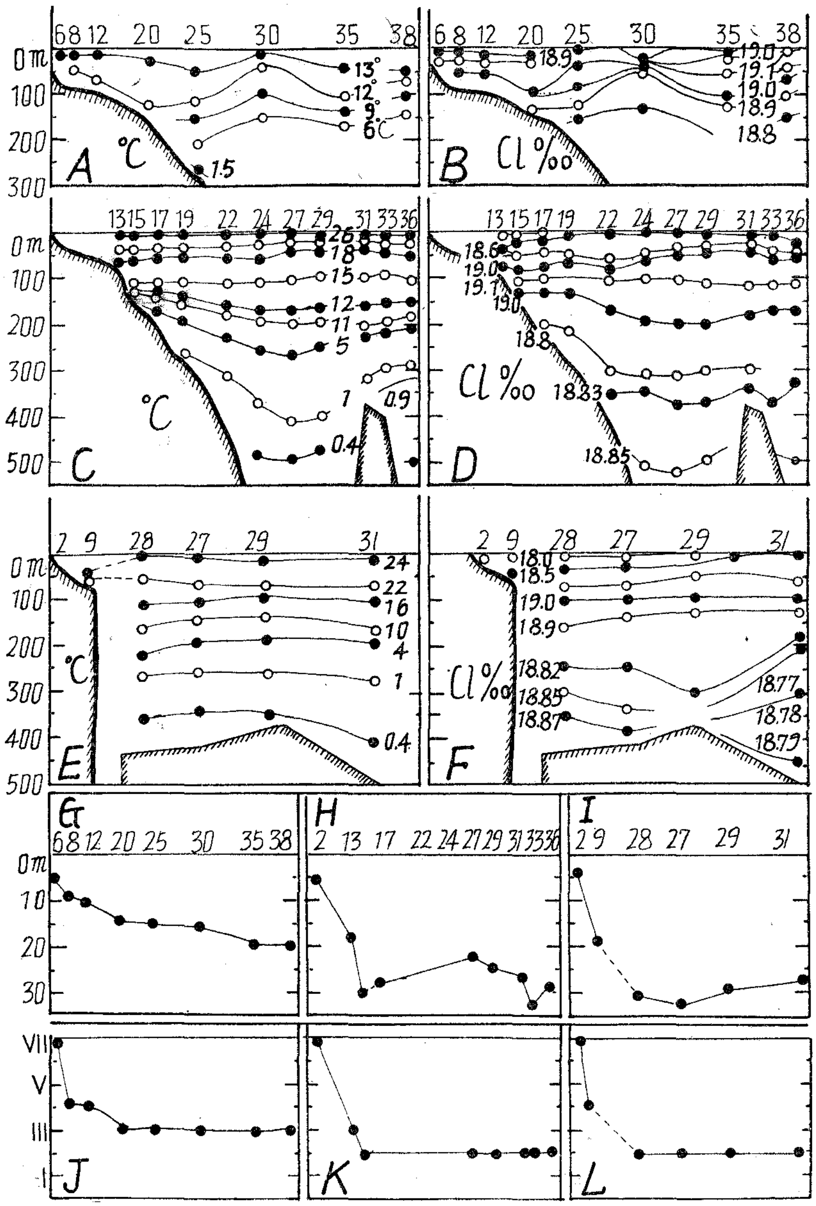

Fig. 3. Hydrological conditions from Maizuru Bay to New Yamato Bank during three cruises in 1950, no. 1.

A, C and *E*: Sectional distribution of water temperature in April, July and September, respectively.

B, D and *F*: Sectional distribution of chlorinity of sea water in April, July and September, respectively.

G, H and *I*: Distribution of transparency at section in April, July and September, respectively.

J, K and *L*: Distribution of water color at section in April, July and September, respectively.

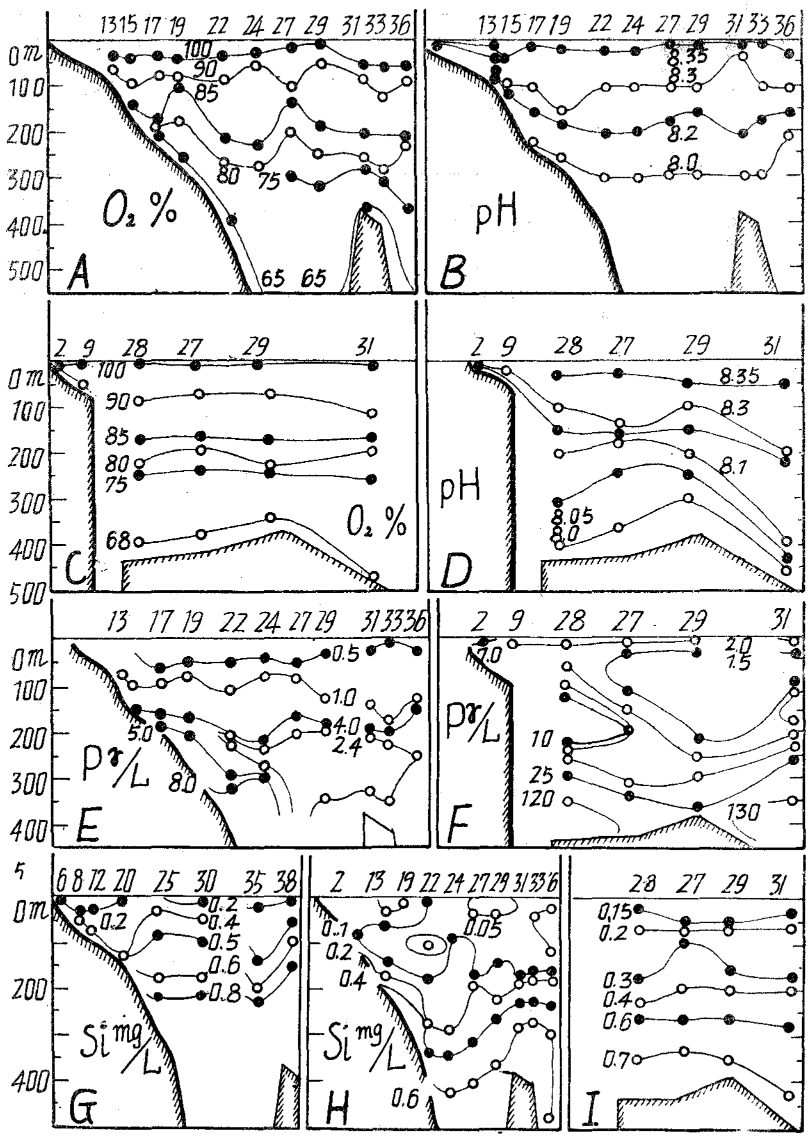

Fig. 4. Hydrological conditions from Maizuru Bay to New Yamato Bank during three cruises in 1950, no. 2.

A and *C*: Sectional distribution of percentage saturation degree of oxygen in July and September, respectively.

B and *D*: Sectional distribution of pH in July and September, respectively.

E and *F*: Sectional distribution of phosphate contents (P_2O_5 γ/L) in July and September, respectively.

G, *H* and *I*: Sectional distribution of silicate contents (SiO_2 mg/L) in April, July and September, respectively.

surface water showed lower values (about 200 mg/m³ SiO_2) than in the bottom water (about 500–800 mg/m³) (Fig. 4, G). As deduced from the values of water color and transparency, the water of Maizuru Bay and Tango Bay (western part of Wakasa Bay) was comparatively turbid but the offshore water far distant from Tango Bay was clear (Fig. 3, G and J). The offshore water seemed to be, as a whole, rather turbid in spring compared with that in summer and autumn, since the smallest values for water color and for transparency were taken during this cruise.

2. Second Cruise (July 24-26, 1950)

In the second cruises undertaken during the mid-summer, the water showed higher temperatures and salinities over the whole area (Fig. 3, C, D). At stations off Kyôga-saki, the temperature was beyond 26°C, from the surface down to 25 m layer and that below 12°C was found only at a depth of 100 m. The isotherm for 12°C was laid at a depth of about 100 m in the coastal waters (St. 9 and 10) and of about 150 m in the offshore waters. The salinity of the surface layer was low, that is, 18.5 Cl ‰ (33.4 S ‰) near Kyôga-saki and 18.3 Cl ‰ (33.06 S ‰) only at St. 36 near the New Yamato Bank, although relatively high at all other stations. The isohaline of 19 Cl ‰ (34.3 S ‰) came up to between 100 and 150 m layer at the four coastal stations (St. 13, 15, 17 and 19), and between 150 and 200 meters at the offshore stations. The chlorinity lower than 19.0 Cl ‰ (34.3 S ‰) was found at 50 m upwards and about 200 m downwards. The isolines of the temperature, salinity and oxygen content under 150 meters rise slightly up along the continental shelf by upwelling of deeper water.

The horizontal and vertical distribution of dissolved oxygen content is shown in Fig. 4, A. The oxygen content was nearly uniform throughout all strata. The saturation degree of oxygen content was relatively high, more than 90 % (about 5.0 cc/L) at 100 m upward, 75 % (about 5.4 cc/L) at 300 m upward, and about 65 % (about 5.5 cc/L) in the bottom stratum of the continental shelf and on the New Yamato Bank at about 350 m depth. It is thus clear that the oxygen content is minimum at the surface and maximum at the depth of 150–300 meters. The pH value varied from 8.35 to 8.0, decreasing according to the depth (Fig. 4, B). The distribution of pH 8.3–8.35 was located at the depth from 0 to 100 m, the pH 8.0 at about 200 to 300 m. The phosphates and silicates were larger in in the lower layer than in the upper layer (Fig. 4, E). These values varied 0.5–1.0 P_2O_5 γ/L and 50–100 SiO_2 mg/L between 0 and 100 m, 3–8 P_2O_5 γ/L and 2000–4000 SiO_2 mg/L between about 100 to 300 m, and 6000 SiO_2 mg/L at the lower layer. These values were comparatively lower than those observed in April at equivalent levels. The water color and transparency were No. 8 of FOREL's scale and 5 m of SECCHI's disc respectively in Maizuru Bay, and No. 2 of FOREL's scale and about 25 to 30 m of SECCHI's disc respectively off Kyôga-saki (Figs. 3, H and K).

3. Third Cruise (September 25-28, 1950)

During the third cruise in autumn, the hydrological observations were made mainly at the stations located within the area of coastal water and also at the offshore stations near the Bank. The surface water temperature ranged from 23°C to 25°C at all stations. In the offshore water overlying the Bank, the temperature descends from the surface to the deeper layer uniformly anywhere, the 20°C isotherm lying between 50 m and 100 m, and the 10°C isotherm at 150 m in depth. In deeper layers than 200 m, the temperature was less than 4°C as in July and below 300 m a temperature of less than 1°C was found (Fig. 3, E). The salinity of the surface layer was about 17.7–17.9 Cl ‰ (31.9–32.2 ‰) in Maizuru Bay, while about 18.5 Cl ‰ at stations on the Bank. On the Bank the isohaline for 19.0 Cl ‰ was found at 100 m, and that for 18.82 Cl ‰ (34.00 S ‰) between 200 and 400 m, and 18.87 Cl ‰ (34.09 S ‰) at the depth of 400 m near the bottom (Fig. 3, F). At St. 4 it was fairly 18.7–18.9 Cl ‰ (33.7–34.1 S ‰), corresponding with that between 200 m and 400 m on the Bank.

The surface water of Maizuru Bay was oversaturated with oxygen, while the offshore water at all stations was undersaturated from surface to depths (Fig. 4, C). The oxygen content was minimum at the surface and maximum at the depth of 150–200 m layer as in July. The pH value decreased toward the bottom (Fig. 4, D). The phosphate content of the coastal water was only 7 γ/L. In the offshore water on the Bank, it was very poor at the surface, while in the deeper layers, attained about 130 γ/L (Fig. 4, F). The silicate content increased also to lower strata (Fig. 4, I). As shown in Table 1, in the offshore water the value of the catalytic activity was larger than in the coastal water, and it increased toward the deeper layers at each station. The largest value was shown at 5 m depth in Maizuru Bay, at

Table 1. Catalytic activity of sea water—$K_{30°C}\cdot 10^3$ (September, 25-28, 1950)

Depth (m) \ Station	2	9	27	31
0	15	17	26	24
5	34	21	—	—
10	22	63	26	25
25		64	87	75
50		59	48	43
100			366	79
150			308	96
200			125	85
250			154	—
300			53	150
350			33	—
400			—	88

25 m depth of Tango Bay, at about 100–150 m depth at St. 27, and about 300 m depth at St. 31.

The water color by FOREL's scale ranged between Nos. 2–7 (Fig. 3, L), and the transparency varied from 4 m to 30 m (Fig. 3, I). The lowest was obtained in Maizuru Bay, and the highest at all stations on the Bank (Fig. 3, I and L).

General Hydrological Conditions

The general hydrological conditions of the Japan Sea have been fully discussed by MARUKAWA & KAMIYA (1926), SUDA et al (1931, 1932 a–b), UDA (1934 a–b, 1936) and MIYAZAKI (1953). As regards the Wakasa Bay and its adjacent areas particularly concerned with this paper, some hydrological observations have already been made in detail by KAMIYA & KUWANA (1925), UDA (1932) and the Maizuru Marine Observatory (1950 a–c, 1952 a–c).

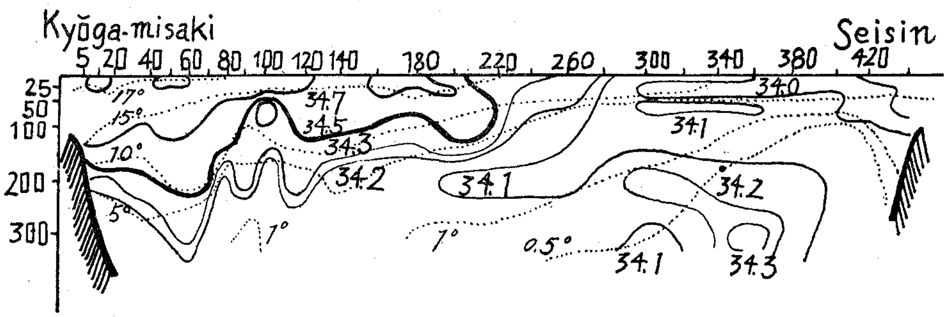

Fig. 5. Water temperature and salinity at section from Kyôga-saki to Sei'sin observed by Kyoto Fish. Inst. on July 5-7, 1932 (after UDA, 1934).

From these previous reports, we recognize that in the seas adjacent to Wakasa Bay, particularly the area off the cape Kyôga-saki, a discontinuity layer lies between depths of about 100 m and 200 m, and that this depends upon the stratification of water masses of different nature. Namely, the warm water-mass of high salinity and temperature belonging to the Tusima Current-system overlies the cold water-mass of low salinity and temperature, which comes from the Liman—North Korea Current-system across the western part of the Japan Sea in a SSE direction. Below the depth of 400 m, the water-mass is almost uniform during all seasons. Our hydrological observations made during three cruises nearly coincide with these previous records.

The New Yamato Bank is a submerged, flat-topped plateau lying below 400 m depth, and thus the Bank itself does not form any obstacle to affect on the water current of this region.

From the planktological point of view, our special interest in the current-system is to know to what extent the disturbance or accumulation of plankton population may take place in consequence of the yearly cycle of hydrological conditions, since the boundary between the cold and warm water-masses fluctuates from month to month, both horizontally and vertically.

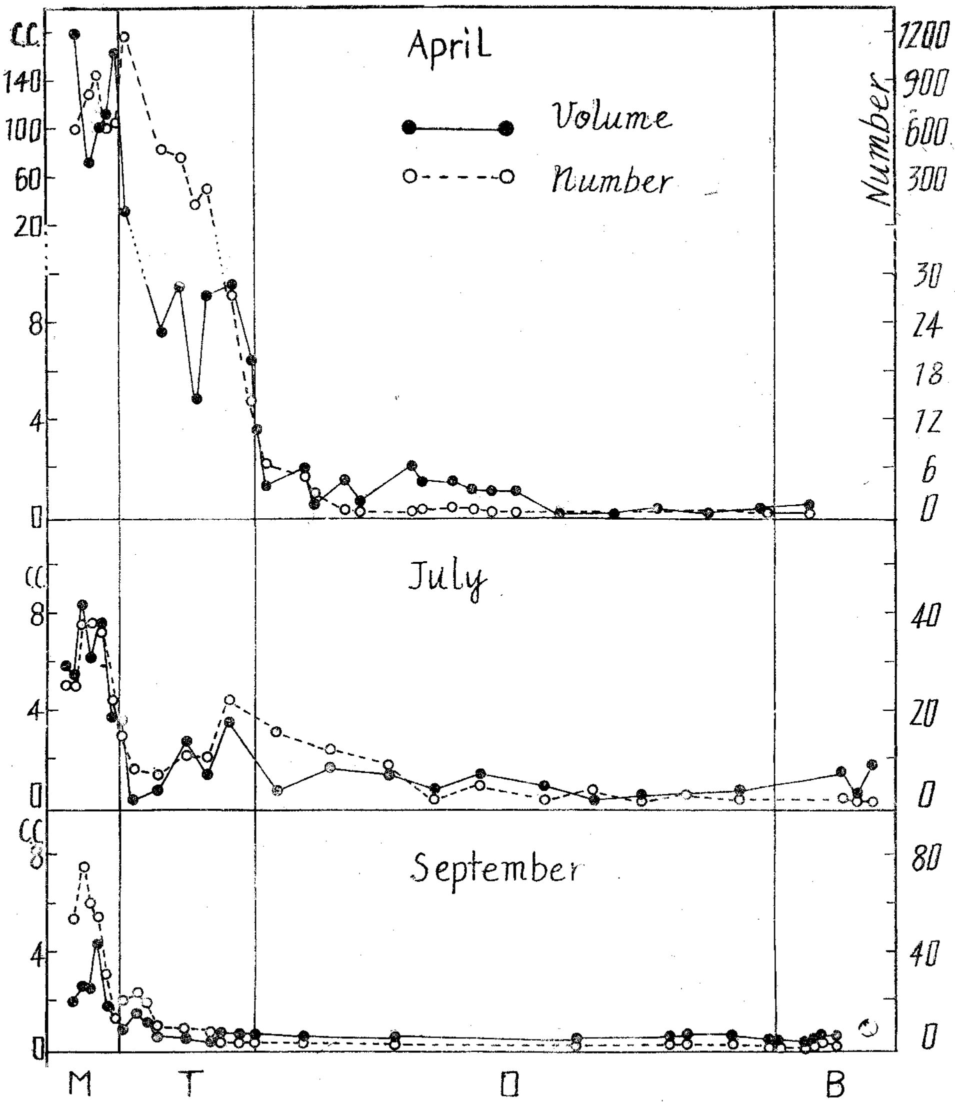

Fig. 6. The relation between the settling volume (cc) of plankton and the number of individuals, cells or colonies (each per 10 minute hauls of superficial layer by the cruise plankton collector) during three cruises from Maizuru Bay to the New Yamato Bank. M=Maizuru Bay, T=Tango Bay, O=Offshore water, B=New Yamato Bank. (These legends at base apply to all forthcoming figures.).

Plankton

A. Quantitative Distribution of Plankton

As is presented graphically in Fig. 6, the relation between the settling volume and total number of individuals, cells or colonies of total plankton caught by the

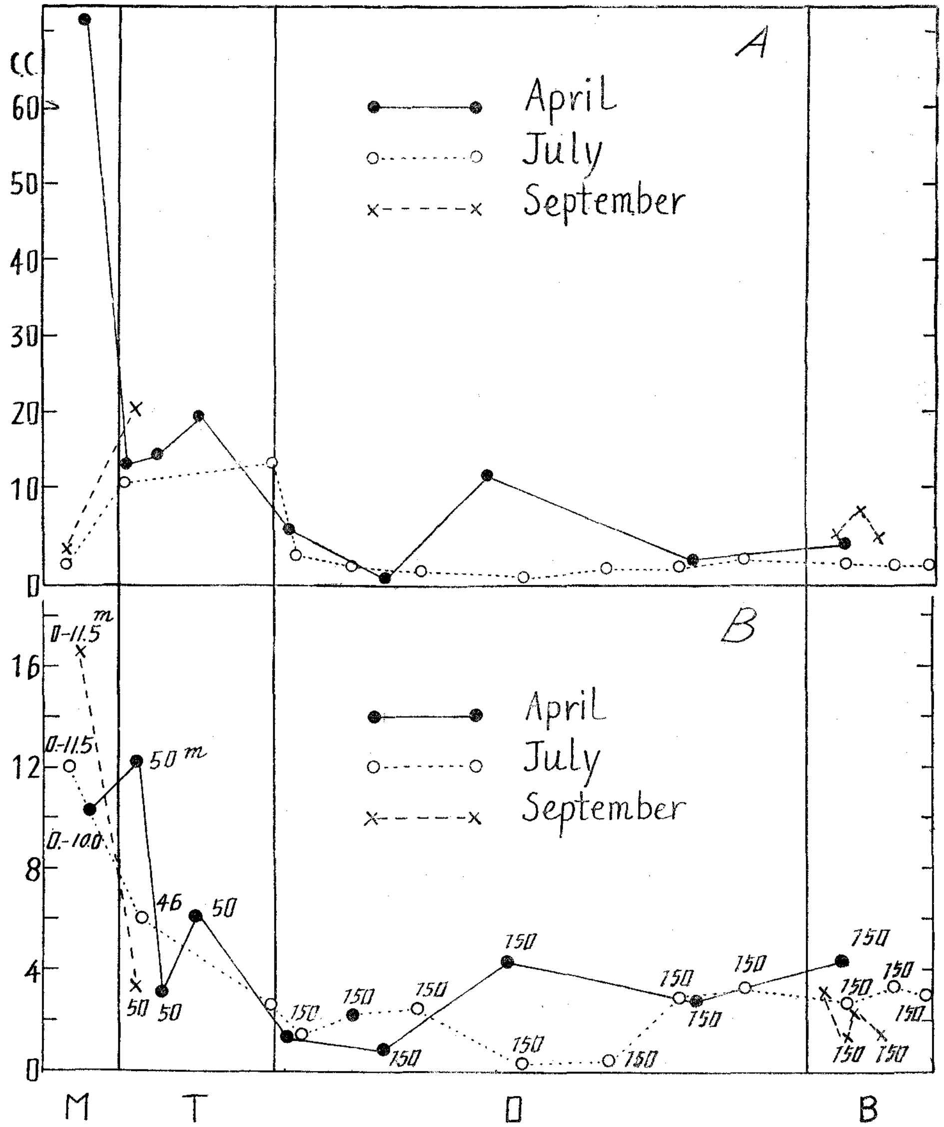

Fig. 7. A, Settling volume of plankton in vertical haul from the surface down to 10-150m depth (each per 10m hauls).
B, Total number of zooplankton in vertical haul from the surface down to 10-150 m depth (numerals indicate the length of haul in 10 meters).

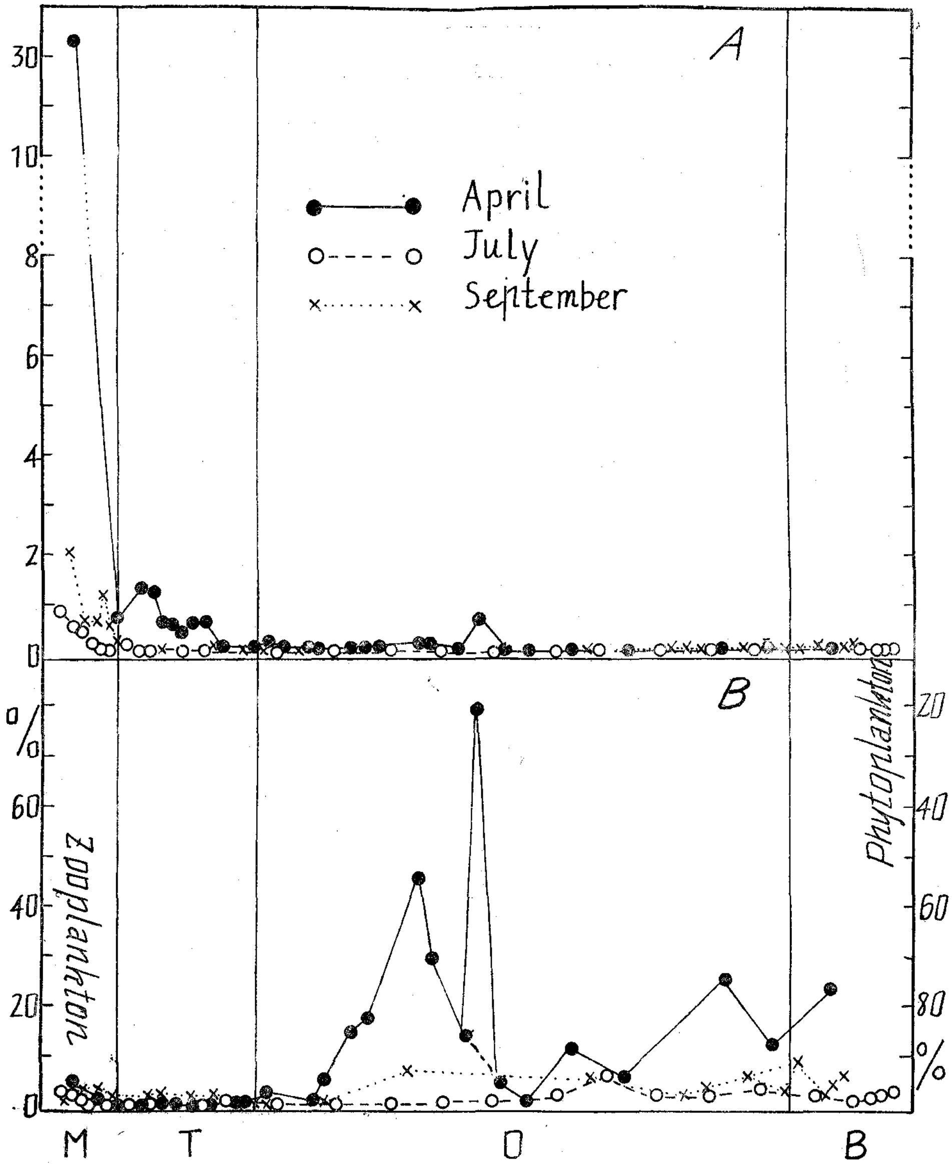

Fig. 8. A, Total number of zooplankton at the stations of superficial haul (each per 10 minutes haul). B, Ratio between zoo- and phytoplankton. Unit of number is thousand.

cruise tow-net from the surface water was almost the same at all stations in the offshore water, in every cruise. The settling volume was very small, less than 2 cc per 10 minutes haul. In the coastal water, however, it is not so close. This is possibly due to the variations in the plankton composition, as will be discussed later. The results obtained from the vertical hauls also present the similar tendency to the foregoing (Fig. 7).

These data point once again to characteristically the greater richness in the coastal area as compared with the offshore area. Within the coastal area, plankton were always the most abundant in Maizuru Bay and intermediate in the coastal area of Tango Bay and near Kyôga-saki. Furthermore, these figures clearly indicate the existence of a seasonal variation in richness in the coastal area. Although our present data unfortunately lack the record during the cold period, the hauls of smallest volume occurred in September and largest in April. According to the serial observation off Kyôga-saki made by the Maizuru Marine Observatory in winter, the plankton as a whole here reached its smallest during winter, the average volume being 1.03–1.71 cc/m³ during winter and 5–10 cc/m³ during summer. However, the volume greatly increased to about 50 cc/m³ in March only when spring diatom flowerings occur (Maizuru Jour. Ocean., vol. 1, no. 3/4, p. 4, 1952).

When the phyto- and zooplankton were treated separately, the numerical

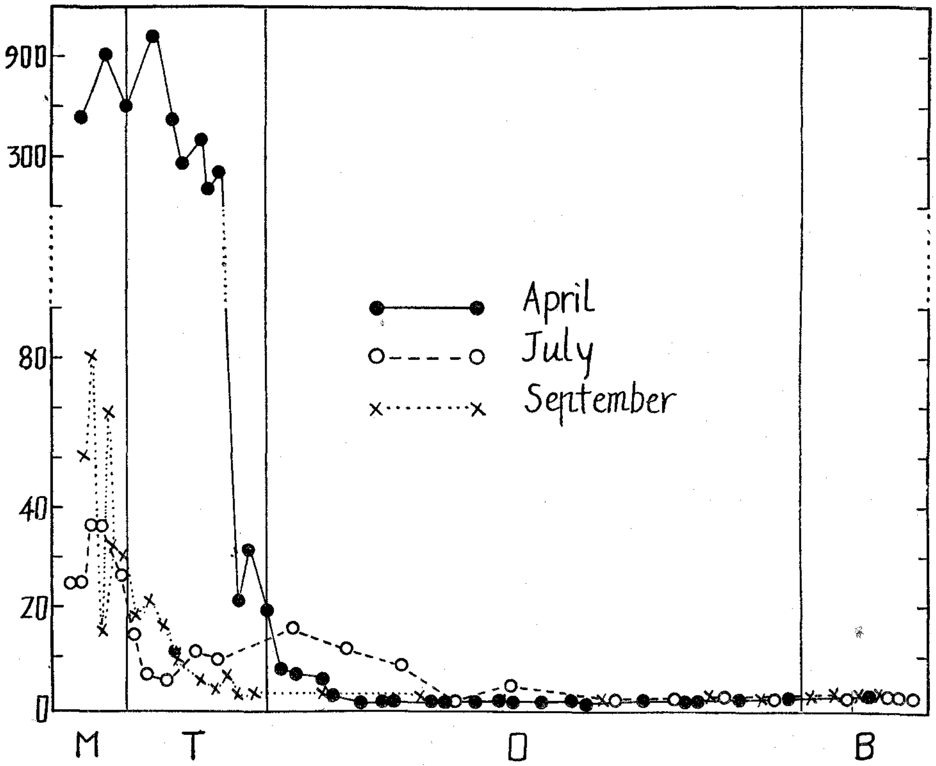

Fig. 9. Total number of phytoplankton at the stations of superficial haul (each per 10 minutes haul). Unit of number is thousand.

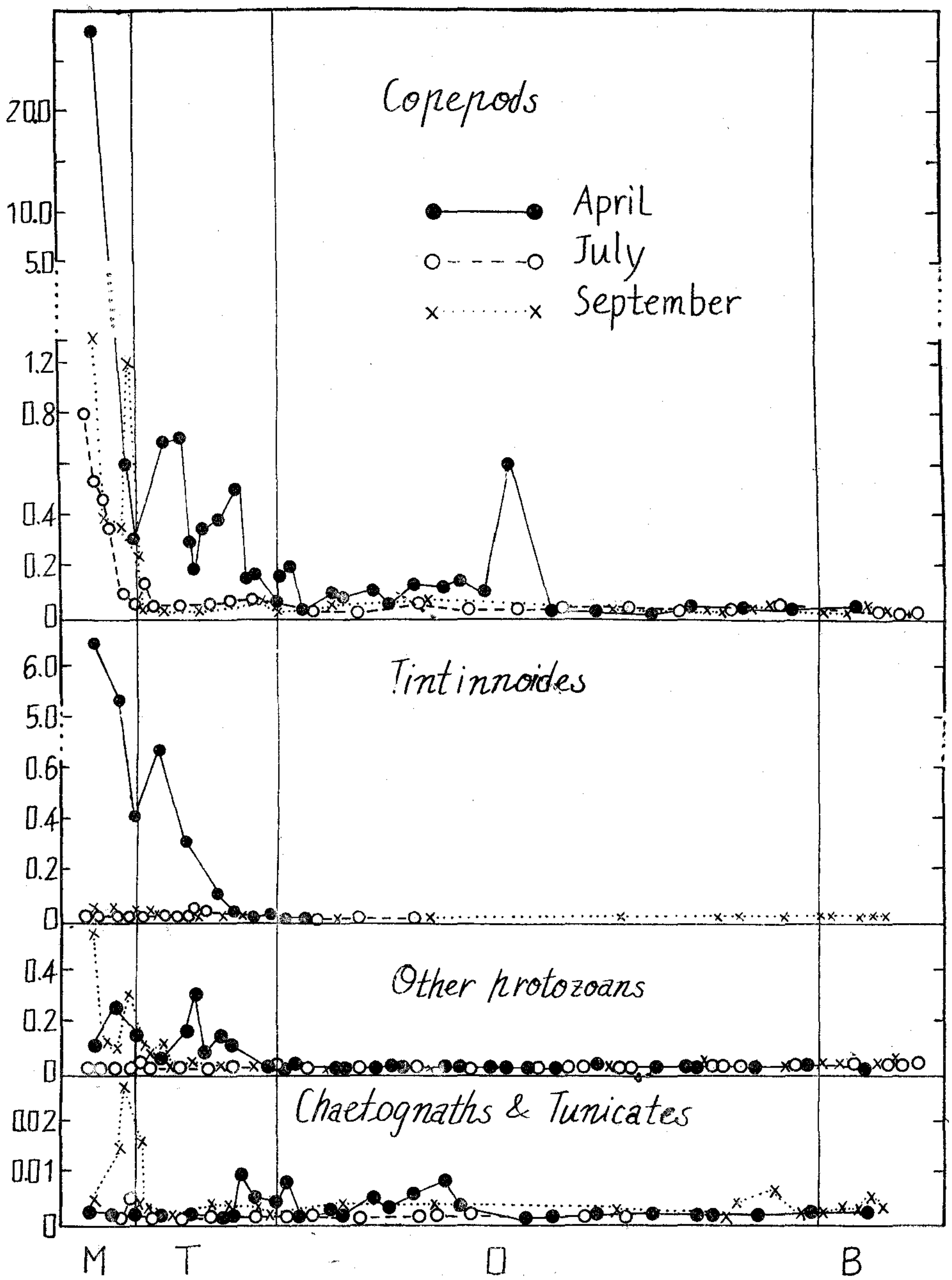

Fig. 10. Individual number of important groups of zooplanktons at the station of superficial haul (each per 10 minutes haul). Unit of number is thousand.

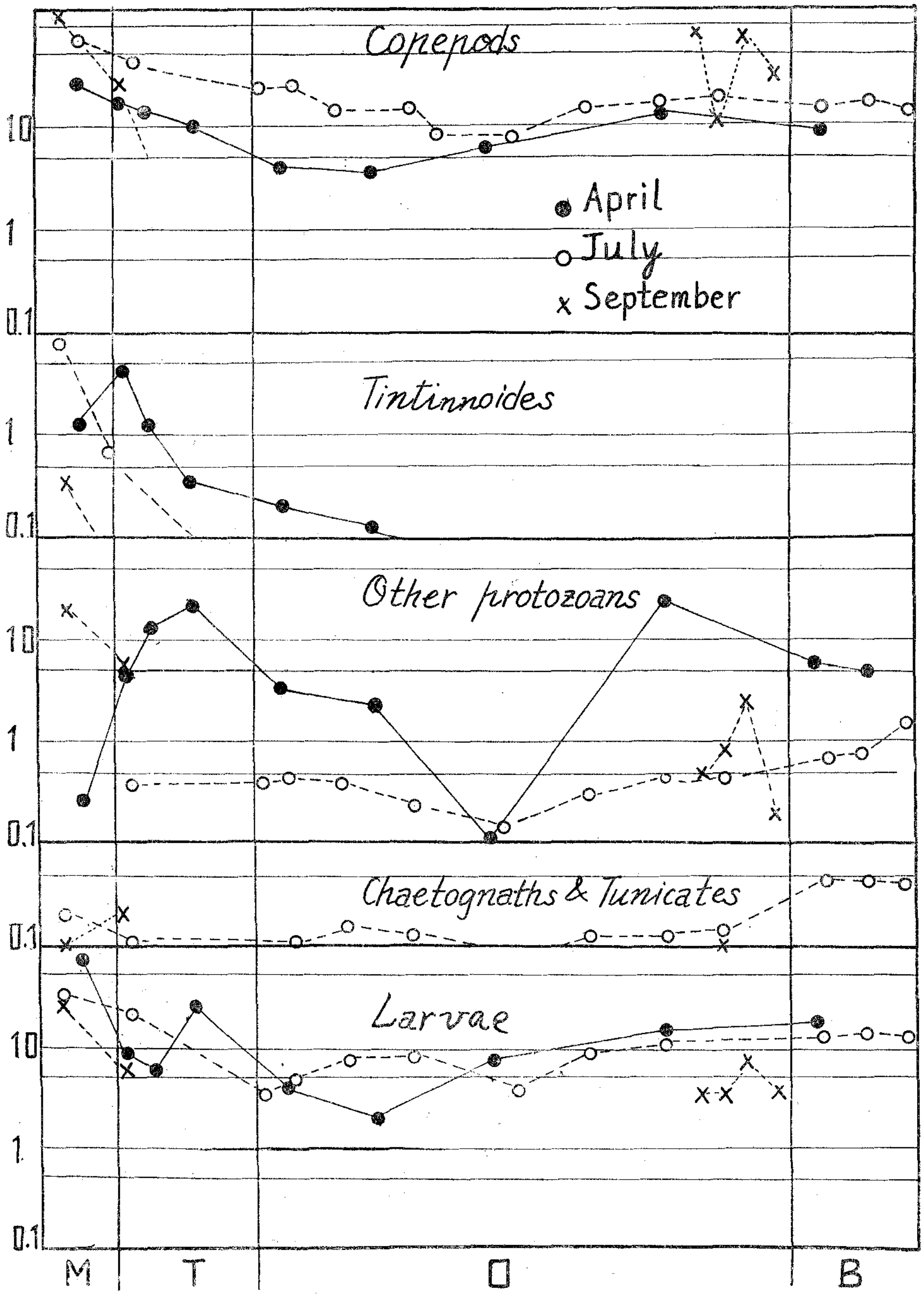

Fig. 11. Individual number of important groups of zooplankton at the stations of the vertical haul. Unit of number is thousand.

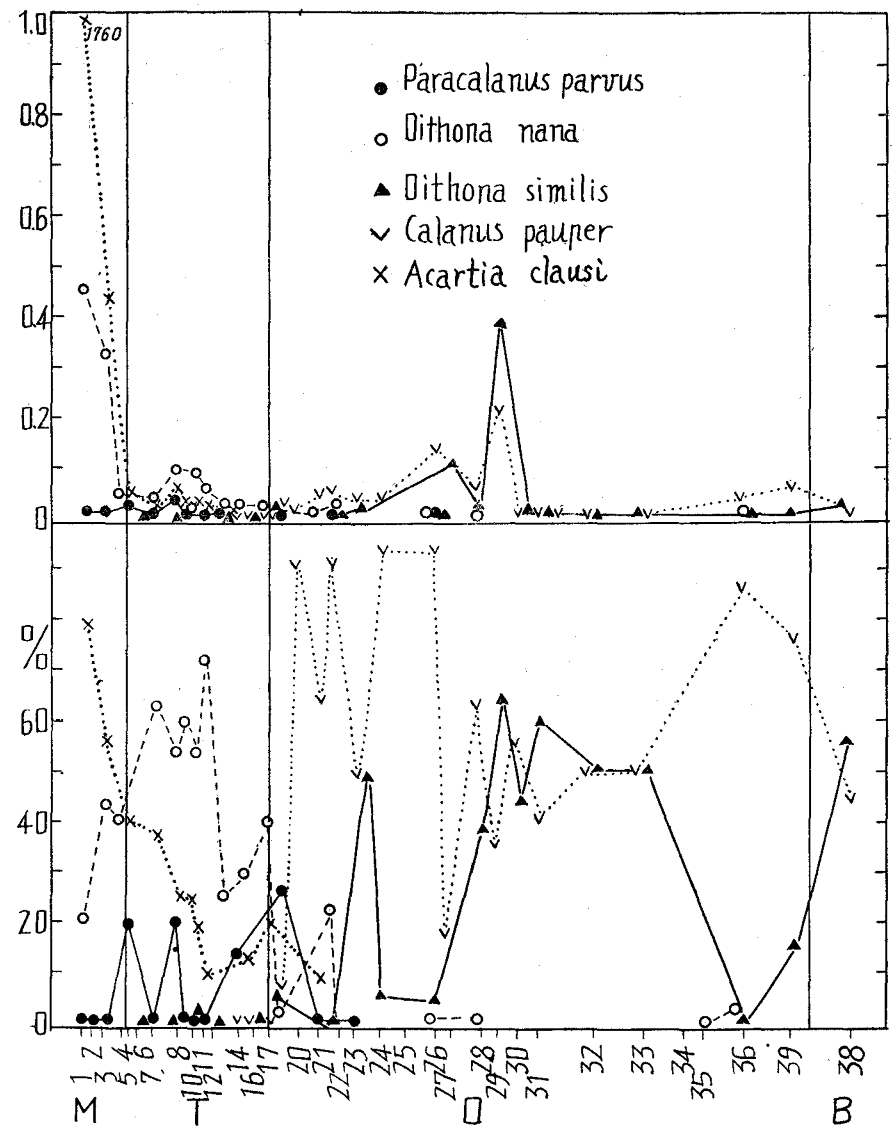

Fig. 12. Number of important copepods per 10 minutes supeficial haul (above), and percentage composition (below) on April, 27-28, 1950. Unit of number is thousand.

percentage of zooplankton in the total plankton (Z/N×100) was very small as a whole, except for the offshore area in April, where it reached 80 % (St. 29), and in the coastal area less than 5 % in every cruise (Fig. 8, below). The population of phytoplankton (Fig. 9) was very rich in the coastal water, particularly in April, as compared with that of zooplankton (Fig. 8, above). However, it decreased abruptly in July and further in September, as described also by AIKAWA (1936 b, p. 105).

B. Qualitative Distribution of Plankton

Zooplankton

The main part of zooplankton was occupied by copepods and followed by other components of small quantity, such as tintinnoids, cladocerans, hydromedusae, chaetognaths and the larval forms (Figs. 10, 11). Among the important copepods, *Oithona nana*, *Acartia clausi*, *Paracalanus parvus* and their nauplii were generally rich in the coastal area. Other calanoids, *Oithona similis*, *Oithona plumifera*, *Oncaea candacia*, etc. were found mainly in the offshore water off

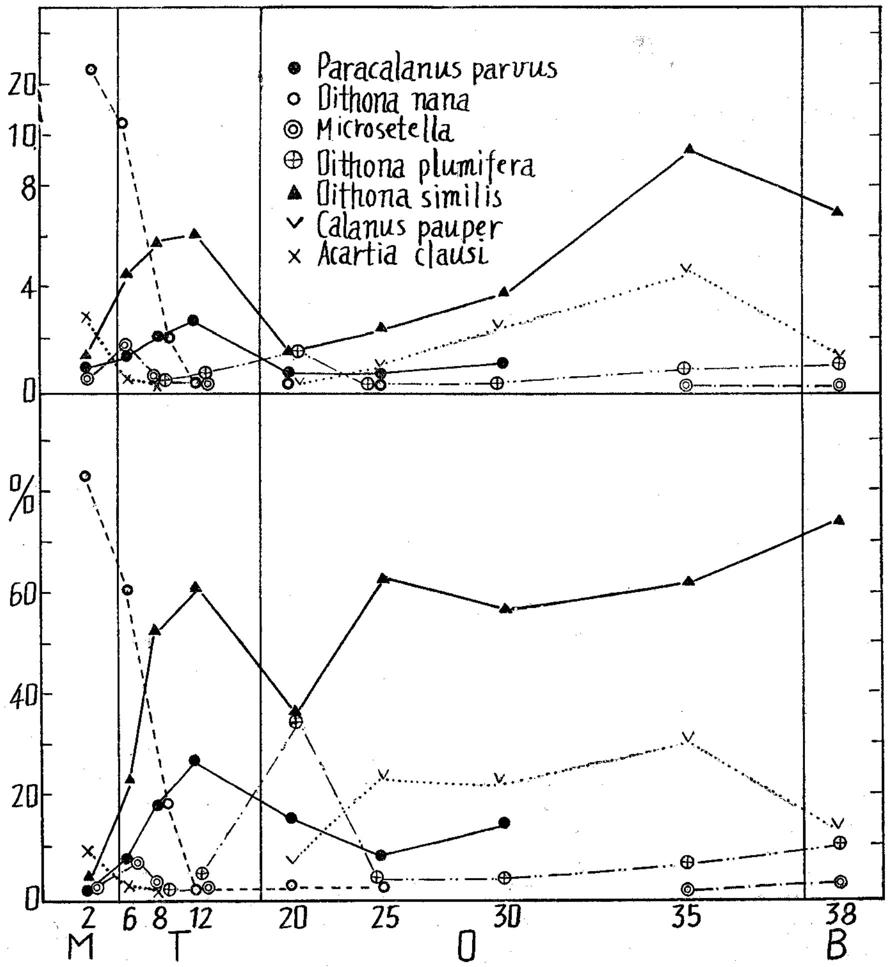

Fig. 13. Number of the most important copepods per 10 m vertical haul from the surface to 10-350 m depth (above) and percentage composition (below) on April 26-28, 1950. Unit of number is thousand.

Kyôga-saki, though not so abundant as in the foregoings (**Figs. 12–17**). Of these copepods, *Acartia clausi*, which is an indicator species of inlet or bay water, was found by far abundantly in April in Maizuru Bay, decreasing abruptly outwards. *Oithona nana*, which is more euryhaline than *Acartia clausi*, came next in that Bay and Tango Bay, although widely spreading far out of the Bay

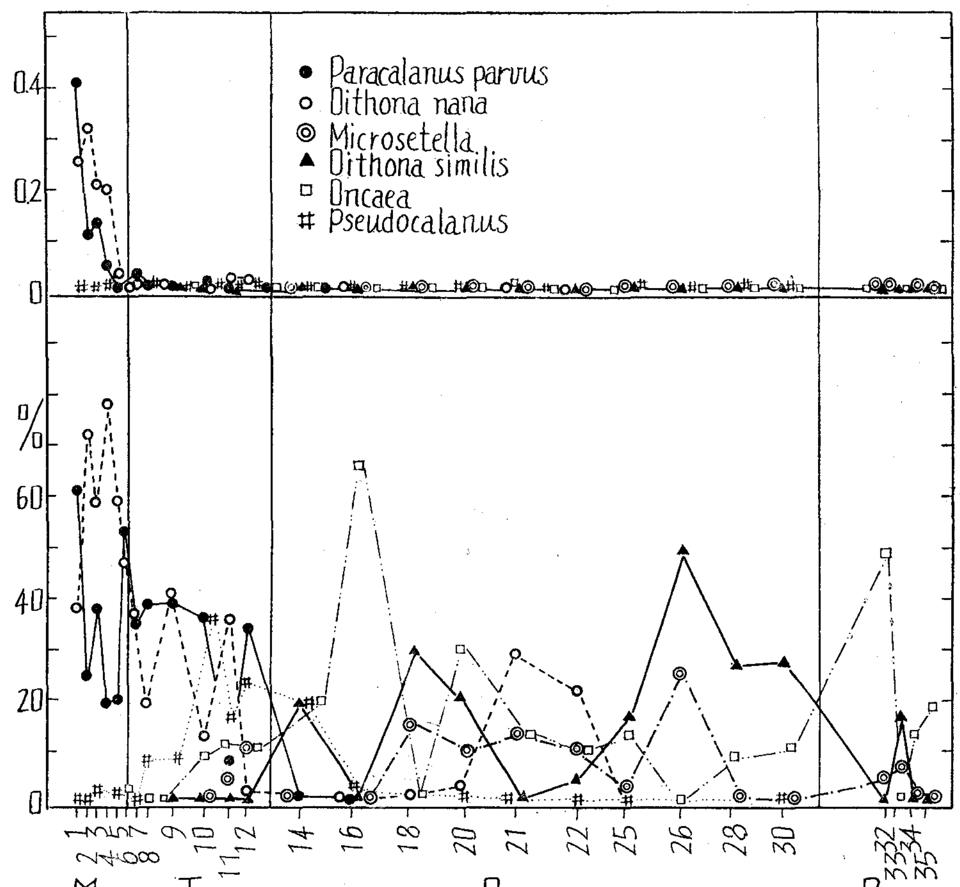

Fig. 14. Number of the most important copepods per 10 minutes superficial haul (above), and percentage composition (below) on July 24-26, 1950. Unit of number is thousand.

sparsely. *Paracalanus parvus* was uniformly distributed in wider areas, but its center of abundance was found to be located within the inner portion of Tango Bay. *Oithona similis*, which occurred widely in Tango Bay and further offshore water, was found during all cruises, and richest in July. *Oithona plumifera* was also observed in every cruise in the same area. The other warm water forms which were scarce but important for the offshore water, are: *Calanus helgolandicus, Cal. minor, Cal. darwinii, Eucal. mucronatus, Mecynocera clausi, Euchaeta flava, Euchaeta plana. Euchaeta ovata, Tortanus forcipatus, Candacia bipunctata, Oithona plumifera* and *Microsetella rosea.* These species were greater in abundance in July and September than in April.

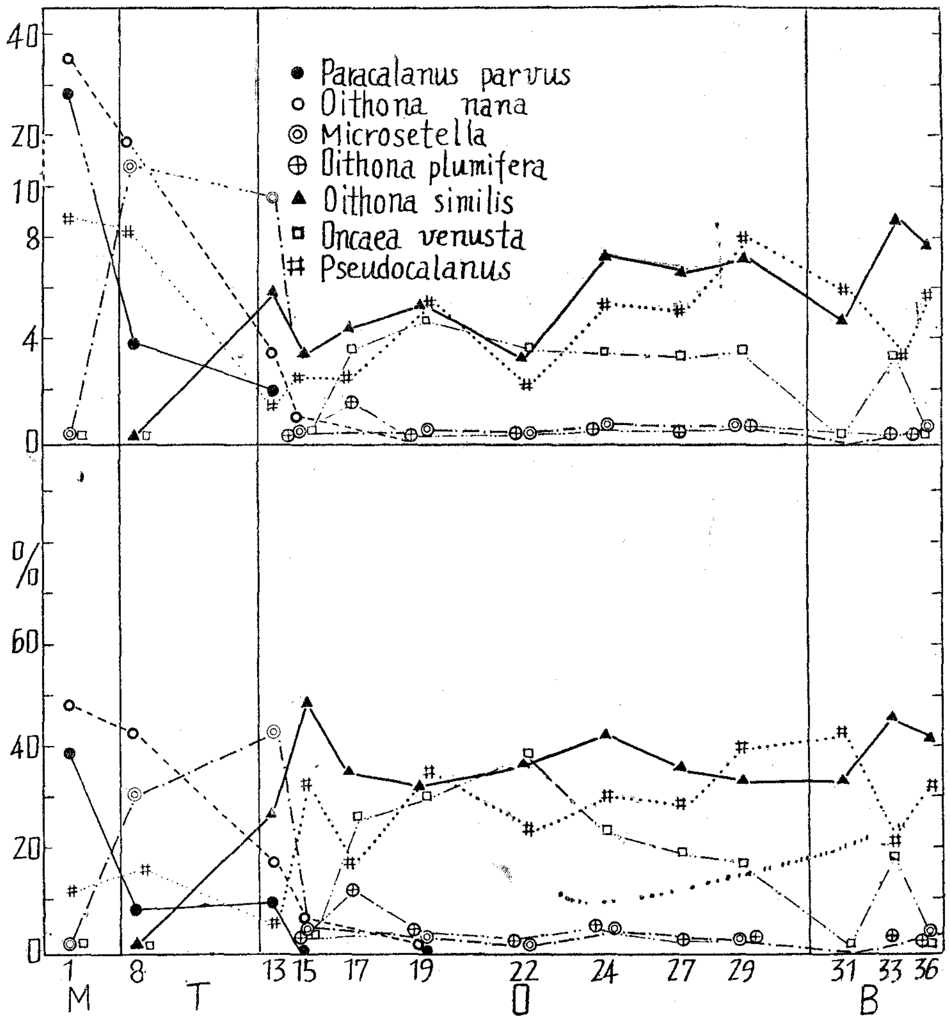

Fig. 15. Number of the most important copepods in the vertical haul from the 10-150 m depth to the surface. Unit of number is thousand, and all hauls combine together for each station (above) and percentage composition (below) on July 24-26, 1950.

The other warm water copepods observed in the offshore waters, though scarce, are as follows:

Oncaea media, Corycaeus longicruris, Cory. crassiusculus, Copilia mirabilis, Copilia longistylis, etc....... July and September.

Cal. tenuicornis, Cal. pauper, Cal. robustior, Eucal. attenuatus, Acartia negligens, etc....... April and July.

Cal. vulgaris, Tortanus forcipatus, etc....... April only.

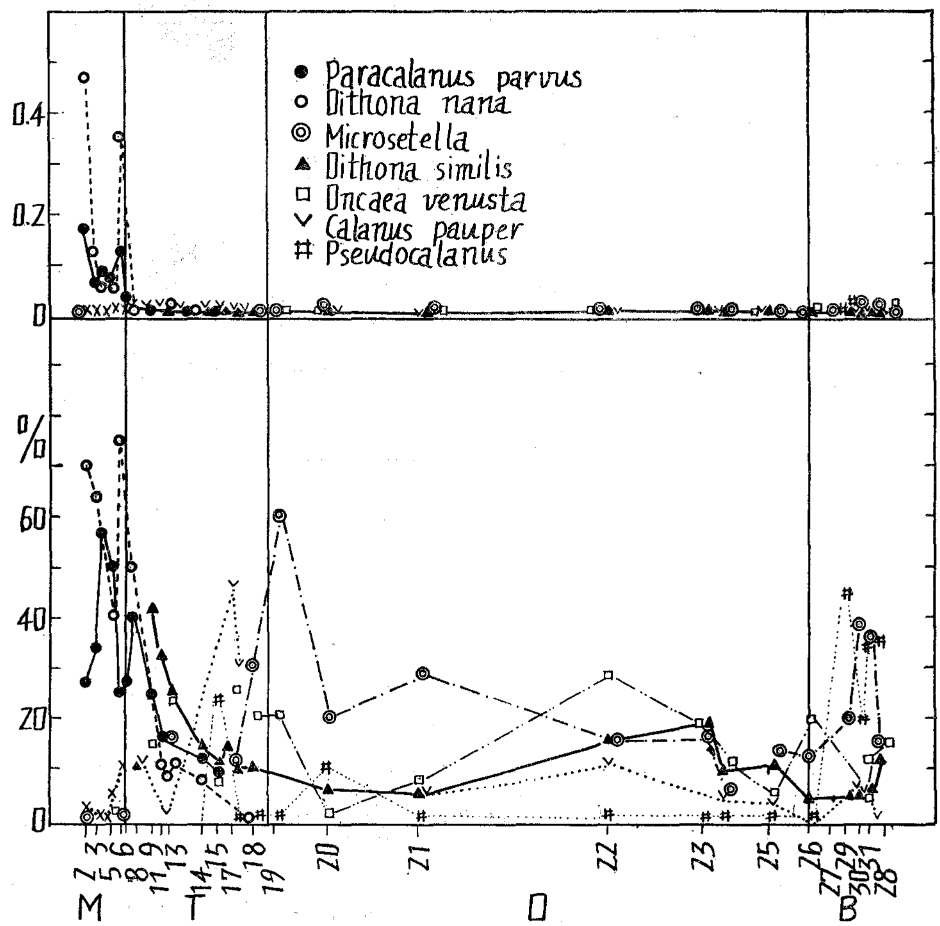

Fig. 16. Number of the most important copepods in the surface haul (above) and percentage composition (below) on September 25-27, 1950.

Besides, it is noticeable to find some cold water forms in deeper strata throughout the year, although not so common as the warm water forms. The representative copepods are: *Calanus cristatus, Cal. plumchrus, Eucalanus giesbrechti, Pseudocalanus elongatus, Pseudocalanus minutus, Metridia lucens.*

Evadne nordmanni, Evadne tergestina, Podon leuckarti and *Penilia schmackeri* are the important cladocerans appeared throughout the period. Other crustaceans, such as *Conchoecia* sp., *Euphausia* sp., *Lucifer raynaudii*, *Vibilia viator*, *Clytomnestra scutellata*, etc. were sporadically found. Most of the chaetognaths, such as *Sagitta enflata*, *S. bedoti*, *S. regularis* and *S. minima* which appeared rather abundantly in the surface hauls, are the warm water species, while *Sagitta elegans* found in the deep layer only belongs to the cold water form. Among pelagic tunicates, such species as *Oikopleura longicauda*, *O. fusiformis*, *O. rufescens*, *Fritillaria*, *haplostoma*, *F. formica*, *F. pellucida*, *F. borealis*, *F. tenella*, etc. were frequent in offshore waters, during the cruises of July and September (TOKIOKA, 1951). *Doliolum nationalis*, a pteropod *Creseis acicula* and several species of hydromedusae were also frequent. Among tintinnoids, *Tintinnopsis beroidea*, *Tint. radix*, *Tin. aperta*, *Favella taraikaensis*, and *Favella* sp. were frequent in the coastal water in April and July. *Favella campanula* was found in September, while *Tintinnus lusus-undae* in July and September.

Acanthometron pellucidum, radiolarians, and *Globigerina bulloides* were also important components of protozoans, appearing in wide areas. *Noctiluca scintillans* and *Dictyocha fibula* were found only inside the bay.

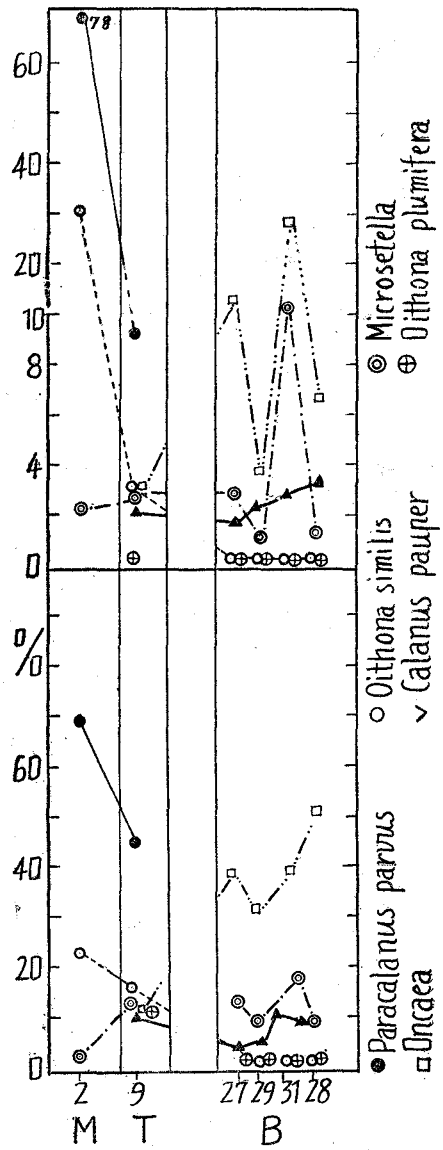

Fig. 17. Number of the most important copepods in the vertical haul (above) and percentage composition (below) on September 25-27, 1950.

Phytoplankton

During all cruises, diatoms dominate the planktonic community everywhere, though quantitatively varied (Figs. 8, B & 9).

Phytoplankton in April: The seasonal variation concerned with the present survey is graphically indicated in Fig. 18. According to Mr. FURUHASHI's observations in Maizuru and Tango Bay, the spring flowering of diatoms begins generally late in January and continues to the end of March. The leading diatoms showing spring flowering are *Chaetoceros* and *Rhizosolenia*. The other diatoms are very small in numerical abundance. The dinoflagellates were represented by 15 species of *Ceratium, Peridinium, Goniaulax, Dinophysis* and *Pyrophacus*, though relatively small in quantity. *Chaetoceros danicus* and *Ch. affinis* were by far predominant in the coastal area, but gradually decreased in number outside. *Ch. compressus, Ch. laciniosus, Ch. didymus, Ch. brevis, Ch. curvisetus, Ch. coarctatus* and *Ch. peruvianus* in the oceanic area come next. Rhizosoleniae were represented by large numbers of *Rh. setigera* and *Rh. hebetata* forma *semispina* and small number of *Rh. stolterfothii, Rh. alata* forma *indica, Rh. alata* forma *gracillima, Rh. imbricata, Stephanopyxis palmeriana, Skeletonema costatum, Leptocylindrus danicus, Hemiaulus sinensis* and *Thalassiothrix Frauenfeldii* were also present, though only in very small numbers.

Phytoplankton in July: The major components were almost similar to those found in April, although varied in abundance and distribution. The populations of *Chaetoceros* in the coastal area showed a marked decrease. Important components were species of *Chaetoceros* and *Rhizosolenia* as well. Among them, *Ch. affinis, Ch. laciniosus, Ch. van Heurckii, Ch. compressus, Ch. Lorenzianus, Ch. decipiens, Ch. pelagicus, Ch. peruvianus, Rh. hebetata* f. *semispina* and *Rh. alata* f. *gracillima* were found most abundantly. *Bacteriastrum hyalinum, Climacodium Frauenfeldianum, Cerataulina Bergonii, Hemiaulus Hauckii, H. sinensis, Thalassionema nitzschioides, Thalassiothrix Frauenfeldii, Th. longissima* and *Nitzschia seriata* were also found.

Dinoflagellates, on the contrary, showed a marked increase and about 30 species were found at all stations in the coastal area. *Ceratium extensum, Cer. carriense* and *Cer. macroceros* were found most abundantly off Kyôga-saki. *Pyrophacus horologicum, Peridinium grande, Cer. tripos, Cer. macroceros* and *Cer. massiliense* were widely distributed. *Per. oceanicum* var. *oblongum, Per. depressum, Cer. fusus* var. *strica* and *Cer. inflexum* were restricted only to the inlet or bay waters of the coastal area.

Phytoplankton in September: The phytoplankton were dominated by diatom and dinoflagellates as well. The leading species of diatoms are *Chaetoceros* spp. and *Rhizosolenia* spp. and *Bacteriastrum hyalinum, Ditylum Brightwellii,*

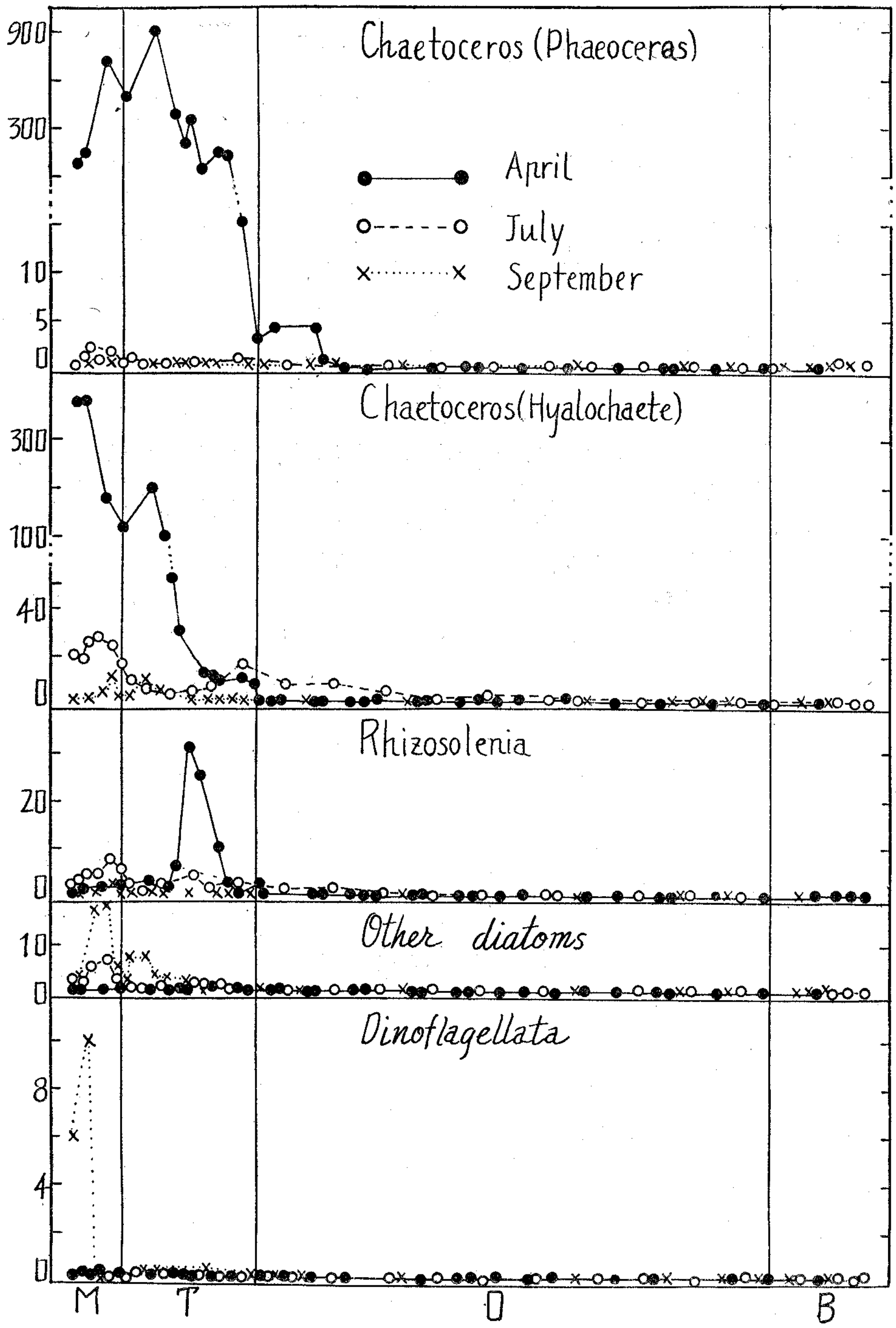

Fig. 18. Number of important groups of phytoplankton at the stations during these cruises.

Dactyliosolen mediterraneus, Dac. antarcticus, Thalassionema nitzschioides, Thalassiothrix Frauenfeldii and *Nitzschia seriata.* Among *Chaetoceros, Ch. laciniosus, Ch. curvisetus, Ch. van Heurckii, Ch. compressus, Ch. didymus* and *Ch. Lorenzianus* were quite numerous in Maizuru and Tango Bay. *Ch. coarctatus, Ch. tetrastichon, Ch. dadayi* and *Ch. convolutus* were found in the offshore water, but they were very sparse. *Rhizosolenia setigera, Rh. hebetata* f. *semispina, Rh. calcar-avis, Rh. alata* f. *gracillima, Rh. alata* f. *indica* were evenly distributed there, and *Rh. cylindrus, Rh. Bergonii, Rh. stolterfothii, Rh. styliformis* and *Rh. acuminata* occurred in Tango Bay and further off the coast.

Dinoflagellates were as abundant as in July, and represented by about 40 species during this period. Among them, *Ceratium furca* was the most prominent. Its distribution was restricted to the coastal water, abundantly in Maizuru Bay, and sparsely in Tango Bay. *Dinophysis caudata, Pyrocystis noctiluca, Pyr. lunula, Ceratocorys horrida, Pyrophacus horologicum, Amphysolenia bidentata, Peridinium grande, Ceratium fusus, Cer. extensum, Cer. Kofoidii, Cer. gibberum* f. *sinistrum, Cer. tripos, Cer. pulchellum, Cer. trichoceros, Cer. inflexum, Cer. intermedium* and *Cer. massiliense* were widely distributed.

Generally speaking, the inshore area such as Maizuru Bay and Tango Bay was dominated by the neritic phytoplankton, mostly belonging to *Chaetoceros.* Other diatoms and dinoflagellates were comparatively few in number. The phytoplankton in the offshore water off Kyôga-saki were markedly poor as compared with Tango Bay. In offshore water, neritic diatoms were also found scarcely. In Tango Bay where phytoplankton were numerically greatest, some offshore forms were found in the central portion and formed a mixed population with the neritic forms which are richer than the former.

C. Number of Species

From the number of species appeared in the superfical haul at every station as shown in Fig. 19, seasonal changes of the plankton composition may be recognized. Upon comparing the successive changes at each station, it will be noticed that phytoplankton were more abundant than zooplankton in quantity during every cruise and that the largest number was obtained in September and the smallest in April. With reference to the regional distribution, the phytoplankton on the whole was the richest in Tango Bay and poorest in Maizuru Bay.

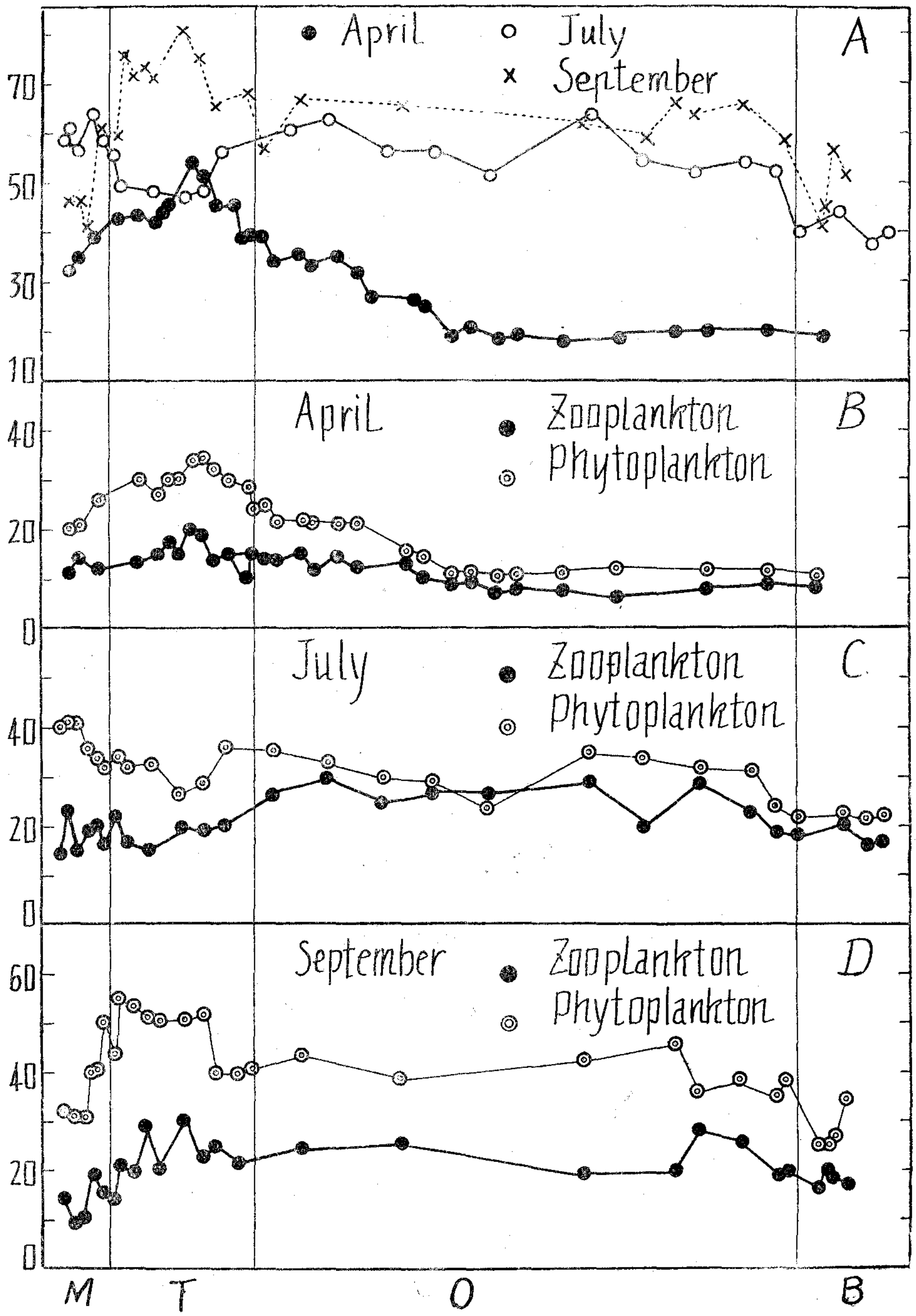

Fig. 19. Number of species in the superficial haul. A, Total number of species during cruises of April, July and September. B. Number of species of zoo- and phytoplankton, on April 26-28, 1950. C, Number of species of zoo- and phytoplakton, on July 24-26, 1950. D, Number of species of zoo- and phytoplankton on September 25-27, 1950.

Discussion

A. Properties of Offshore Plankton

The plankton community occurring in the southern part of the Japan Sea, is influenced by both the cold and warm currents, the Liman—North Korea Current flowing from north and the Kurosio—Tusima Current flowing into the Japan Sea from the Korea Strait. The planktological investigations in this region have been made mainly by MARUKAWA (1928), KURASIGE (1932 a, b), YAMADA (1933 a, b, 1936), AIKAWA (1930, 1934, 1936 a, b) and TOKIOKA (1940). First of them, MARUKAWA (1928) considered that the plankton of the region consists of two elements, (1) the native species such as *Calanus plumchrus, Oithona similis, Paracalanus parvus, Pseudocalanus elongatus,* etc., which are found everywhere and every season, and (2) the exotic species, such as *Halosphaera viridis, Trichodesmium Thiebautii, Sticholonche zanclea,* etc. which are found only in the area influenced by the warm Tusima Current.

The admixture in various proportions of both the cold and warm water forms is seen in the area adjacent to Uturyô-tô (Dageret Island) to some extent (KURASIGE, 1932 a, b; YAMADA, 1933 a, b; TOKIOKA, 1940). According to these authors, the main component of plankton found in the mixed area consists of three sources; the warm water species* introduced from the Yellow Sea and the coastal water of southern Korea through the Korea Strait, such as *Sagitta crassa, Parathemisto* sp., *Euchaeta marina, Acartia clausi,* etc. (2) from the Kurosio Current or the coastal water along Kyûsyû, through the Eastern Strait of Tusima, such as *Sagitta bedoti, S. enflata, Doliolum nationalis, Salpa fusiformis, Rhincalanus cornutus, Candacia bipinnata, Calanus mucronatus, Creseis acicula,* etc., and (3) the cold water species, which are prevalent around the northeastern area of Korea, such as *Ceratium bucephalum, C. arcticum, C. longipes, Pseudocalanus elongatus, P. magna, Calanus cristatus, Cal. plumchrus, Metridia lucens, Sagitta elegans,* etc. AIKAWA (1936) pointed out that the warm water forms brought into the Japan Sea through the Tusima Current are mostly of the proper Kurosio group and that the cold water forms of the Liman group in the southern Japan Sea are only driven northwards when the influence of Kurosio Current becomes more vigorous, although reaching as far south as Uturyô-tô in winter to spring.

From the planktological point of view, our interest in the current system of the Japan Sea lies in the fate of the Liman—North Korea Cold Current,

* For convenience sake, the species of diatoms are omitted in consideration herein.

and in the extent to which the cold water forms proper to the said cold current can approach the Japanese coast in the southern part. Some cold water forms (*Calanus plumchrus, Pseudocalanus elongatus, Pseudolovenula magna* and *Parathemisto oblivia*) were found formerly by KURASIGE (1932 a) in small quantities in the southern Japan Sea more southwards than Uturyô-tô, but he gave no much stress on their southward extension of range. It was recently revealed by TOKIOKA (1951) and FURUHASHI (1952 a, b, 1953) too, since several cold water forms were found in the deeper layers off Kasumi and off Kyôga-saki throughout the year, although in a few number for each haul. During our cruises, this fact has been confirmed by vertical hauls. In the offshore water of the region referred to, most of the warm water forms were found in superficial layer shallower than 100 or 150 m and the cold water forms were exclusively in deeper layers, showing a nearly stratified distribution.

1. *Warm water plankton community in upper layers*

Most of the plankton appeared from about 100 m to the surface off Kyôga-saki were the warm water species. These forms are chiefly of the Kurosio Current origin, such as *Oithona plumifera, Oncaea venusta, Calanus darwinii, Cal. tenuicornis, Cal. helgolandicus, Cal. robustior, Eucal. attenuatus, Mecinocera clausi, Euchaeta, Saphirina, Sagitta enflata*, etc. Among oceanic diatoms and dinoflagellates, *Ch. coarctatus, Ch. denticulatus, Ch. atlanticus* var. *neapolitana, Ch. tetrastichon, Ch. dadayi, Rhizosolenia* spp., *Ceratium gibberum, C. platicorna, C. tripos, C. smatoranum* and *C. candelabrum* were dominant. The presence of neritic species, such as *Sagitta crassa* f. *typica, S. crassa* f. *naikaiensis, Oikopleura dioica, Parathemisto* sp., pelecypod and gastropod veliger, Tornaria, Ophiopluteus, *Skeletonema, Stephanopyxis, Nitzschia seriata*, etc. occurring chiefly in the Yellow Sea, the Korea Strait and the western coast of Kyūsyū were also noticeable. It is clear from these records that the water in the upper layer is occupied by the warm water-mass of the Tusima Current which was influenced several times in the course by the inshore waters along the coasts of Kyusyu, southern Korea and San'in district.

2. *Cold water plankton community in deeper layers*

Adjacent to the island Uturyô-tô and near the area on the Yamato Bank (KURASIGE, 1932 a, b), the cold water species are found in the surface layer in summer. During the present cruises any cold water species were not found in the surface. But some cold water species, which were probably originated

Table 2. Vertical distribution of the cold water species found during three cruises.

Date of cruise	April 26-28, 1950					July 24-26, 1950								September 25-28, 1950				
Station	30		35		38	24	27	29	31		33		36	27		28	29	31
Hauled distance (m)	50-0	150-0	50-0	150-0	150-0	150-0	400-200	400-200	150-0	300-150	150-0	350-150	350-150	150-0	350-0	350-0	350-0	350-0
Calanus cristatus																	1	
Calanus plumchrus	2	2		3	16		2	1						1	2		1	7
Eucalanus giesbrechti															1			
Metridia lucens						1	10	1	1		1	2						10
Vibilia viator				1	4													
Aglantha digitale															3	4	2	
Sagitta elegans	2	1						1		1		1	2					
Oikopleura labradoriensis		1		1	1													
Limacina helicina	3	18	5	4	5													

from the Liman—North Korea Current, were obtained below 100 or 150 m depth (Table 2). All of them belong to the zooplankton, and any phytoplankton were not encountered. They are:

Crustacea-*Calanus cristatus*, *Cal. plumchrus*, *Eucal. giesbrechti*, *Metridia lucens* and *Vibilia viator*.

Medusae-*Aglantha digitale*.

Chaetognatha-*Sagitta elegans*.

Tunicata-*Oikopleura labradoriensis*.

Mollusca-*Limacina helicina*.

Besides, FURUHASHI (1952 b) found some cold water plankton animals in samples hauled from the deeper layer during the period from May to August 20–30 miles off San'in district. He also found a large number of the cold water species in the surface haul (0–50 m) from winter to early spring within 1–20 miles off Kyôga-saki, although the warm water species were predominant (Maizuru Mar. Obs., 1952 b). Representatives recorded by FURUHASHI in both reports, besides the above-mentioned species, are as follows: Copepods-*Pseudocalanus minutus*, *Ps. elongatus*, *Ctenocalanus longicornis*, *Ct. vonus*, *Corycaeus japonicus*, *Euchaeta japonica*; Pteropods-*Clione limacina*. Most of them are prevalent in the northern part of the Japan Sea (AIKAWA, 1936 a, b; MOTODA, IIZUKA and ANRAKU, 1950).

On the basis of vertical distribution of general oceanographical factors, UDA (1934 a, b, 1936) distinguished three water layers in the Japan Sea. Namely, (1) the Yellow Sea water with low salinity enters into the Japan Sea from the western side (Korean side) of Tusima Strait and spreads on the surface layer (surface to 20 or 30 m) in wide area of the southern Japan Sea in summer, (2) the warm water of the Tusima Current with high temperature, high salinity, poor nitrates, poor silicates and poorly dissolved oxygen forms the intermediate layer (from 25 m to 200 m depth), and (3) in the deeper layer below about 200 m cold water-mass with low temperature, comparatively low salinity, rich nutrients and richly dissolved oxygen. He (1934 b, p. 99) also commented that the North Korea Cold Current with richly dissolved oxygen and low salinity seems to descend obliquely under the warm water-masses of Tusima Current in the southern part of Japan Sea east of Korea (Fig. 5). From the hydrological observations made during our cruises, the existence of two different water masses distinctly stratified was easily recognized: (1) the upper layer from the surface to 75 or 150 m depth, (2) the lower layer below a depth of 75 or 150 m. The vertical distribution of plankton in the section accords it well.

The occurrence of the cold water forms in the deep layers off San'in district to Kyôga-saki, not too much distant from the coast, may be explained by supposing that the cold water-mass with low temperature and low salinity, originating from the North Korea Current descended deeply below the warm Tusima Current near Uturyô-tô and then flowed further southeastwards to the Japanese coast at the time of freezing. FURUHASHI (cf. Maizuru Marine Observ., 1952 b) found several cold water forms in the subsurface (0–50 m depth) water 14–20 miles off Kyôga-saki in winter (January, March and April). These cold water forms were found in more than 11.0°C (in March) to 13.0°C (in January), as cited above.

However, the vertical distribution of plankton seems to be not persistent throughout the year, but varies from time to time, since a diurnal or seasonal migration is to be expected. Furthermore, if a vertical migration of any animal tended to take place, very different conditions would be met with according to the rise or fall of water temperature (RUSSELL, 1933; CLARKE, PIERCE and BUMPUS, 1943; MOTODA and SATO, 1949). Therefore it seems likely that certain tolerant cold water species of cold current area or deep layer would migrate upwards during the cold season, showing no marked vertical difference in temperature as in the cold water. However, to determine this assumption more important and reliable data should be accumulated by continuous planktological and hydrological observations during at least 24 hours at selected stations of this area in the whole stage of plankton and in different seasons.

B. Horizontal Distribution of Plankton in Tango Bay and Maizuru Bay

Maizuru Bay and the inner part of Tango Bay (western part of Wakasa Bay) were dominated by the inshore copepods and diatoms in every cruise. These inshore forms gradually decreased towards the outer part of Tango Bay, and the poorest off Kyôga-saki, where offshore forms were fairly rich. In the outer area of Tango Bay occurred the admixture of the offshore and inshore species, and the offshore diatoms and animals were not so prevalent as in offshore waters off Kyôga-saki and the inshore forms were poorer than in the inner part and Maizuru Bay, as shown also by FURUHASHI (cf. Maizuru Marine Observ., 1952 c). In these bays and inlet, the plankton community is characterized by the predominance of inshore forms of *Chaetoceros*, other diatoms, animals and of larval forms. Following the method described in my previous papers of this series, some of the dominant species of copepods in relation to their local abundance may be recognized as indicators of hydrological conditions in these bays.

1. *Acartia clausi* and *Oithona nana* community.

In April the strictly inshore and estuarine species *Acartia clausi* and *Oithona nana* were very abundant in Maizuru Bay. The former species was more or less confined to the protected area of the bay, while the latter was widespread towards Tango Bay, though very scarcely in the area distant from the coast. Both species were associated with a large number of *Chaetoceros danicus* and *Ch. affinis* and other species of *Chaetoceros*, the nauplii of copepods, *Tintinnopsis beroidea*, *Tin. radix* and small number of *Paracalanus parvus*. Maizuru Bay is shallow and the water is highly stagnant, showing small transparency, lower salinity and higher value of water color in FOREL's scale than in Tango Bay.

2. *Oithona nana* and *Paracalanus parvus* community.

The plankton community of Maizuru Bay in July and in September as well as that of the inner part of Tango Bay was characterized by the predominance of *Oithoha nana*, *Paracalanus parvus*, *Oithona similis*, *Pseudocalanus*, *Microsetella rosea*, *Acartia clausi* and *Tintinnopsis beroidea* in different frequencies of occurrence. Important phytoplankton associated with them were *Chaetoceros danicus*, *Ch. affinis*, *Ceratium oceanicum* var. *oblongum*, *Cer. pellucidum* in April, *Ch. peruvianus*, *Ch. compressus*, *Ch. didymus*, *Ch. van Heurcki*, *Ch. affinis*, *Ch. laciniosus*, *Ch. pelagicus*, *Ch. brevis*, *Hemiaulus sinensis*, *Thalassiothrix longissima*, *Ceratium furca*, *C. tripos*, *C. masciliense*, etc. in July.

and *Ch. Lorenzianus, Ch. didymus, Ch. laciniosus, Bac. hyalinum, Ditylum Brightwellii, Thalassiothrix Frauenfeldii, Ceratium furca, C. fusus, C. trichoceros* in September.

3. *Paracalanus parvus* and *Oithona similis* community.

Tango Bay was mostly occupied by the inshore copepods, such as *Oithona similis, Oithona nana, Paracalanus parvus, Microsetella norvegica, Micro. rosea* and *Oncaea*, of which the first two were the most abundant. *Oithona similis, Microsetella* and *Oncaea* appeared also in offshore waters in small quantities. This association apparently occupied a wider area in the bay in April and July than in September. The phytoplankton surpassed the zooplankton, both quantitatively and qualitatively, throughout the period and in all areas. The remarkable components of phytoplankton were as follows: *Chaetoceros laciniosus. Ch. affinis, Rh. setigera, Leptocylindrus danicus* and *Thal. Frauenfeldii* in April, *Ch. peruvianus, Ch. decipiens, Ch. Lorenzianus, Ch. van Heurcki, Ch. affinis, Ch. pelagicus, Rh. hebetata* f. *semispina, Rh. calcar-avis, Bac. hyalinum, Climacodium Frauenfeldianum* in July, and *Ch. compressus, Ch. didymus, Skeletonema costatum. Th. Frauenfeldii, Cer. trichoceros* and *C. inflexum* in September. Besides, some offshore species, belonging to *Calanus, Eucalanus, Candacia*, etc. were found in small numbers.

Summary

1. The planktological and hydrological observations were made along the section between Maizuru Bay and New Yamato Bank on board the R. M. S. "Kurosio-maru" of Maizuru Marine Observatory during three cruises in April, July and September, 1950. The samples were collected by the cruise net from the superficial layer at all stations and also by the quantitative net for vertical hauls from 50, 150, 250, 400 meters depths respectively at several stations.

2. The settling volume and total number of plankton varied greatly at different stations and throughout the period. Their relationship was discussed in detail.

3. The quantitative and qualitative distribution of copepods, protozoans, cladocerans, pelagic tunicates, chaetognaths, larval forms, diatoms and dinoflagellates were studied. Their horizontal distribution showed a marked contrast between the offshore (off Kyôga-saki to the New Yamato Bank) and inshore (Tango Bay and Maizuru Bay) areas. In offshore waters, the plankton showed a marked stratified distribution in the appearance of the warm and cold water forms, the boundary between them lying on about 100 to 150 m layer.

4. In the section between Kyôga-saki and the New Yamato Bank, the warm water species of the Tusima Current occurred abundantly in the upper layer from the surface to 50 or 150 m depth, and some cold water species probably introduced by the southerly-trending submerged cold water of the North Korea Current were found only in the lower layer below 150 m depth except one station in the 50 m depth in April.

5. The cold water forms encountered hereabout were represented by 7 crustaceans, 1 medusa, 1 chaetognath, 1 tunicate and 1 pteropod.

6. Vertical stratification of the warm and cold water population apparently suggests the southeastward extension of the submerged Cold Current approaching the Japanese coast especially San'in district, but it may vary according to the diurnal or seasonal migration.

7. In the coastal area of Tango Bay and Maizuru Bay, three combined plankton communities in relation to the horizontal distribution of important copepods were distinguished: *Acartia clausi*—*Oithona nana*—*Paracalanus parvus*—*Oithona similis*. These communities were mixed from area to area and the center of distribution for each community gradually changed seawards in order.

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