PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

VIII. THE PLANKTON OF MIYAZU BAY IN RELATION TO THE WATER MOVEMENT[1)2)]

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With 16 Text-figures

With the object of studying the plankton community in relation to the water movement, field work was made on two occasions in Miyazu Bay, a small inlet of Wakasa Bay along the coast of the Japan Sea. The first survey was made on June 3rd, 1945 and the second on September 29th, 1950. A preliminary account, dealing with the benthic and planktological data obtained during the first survey, was given elsewhere by HABE & YAMAZI (MS). The present note is based chiefly on the second survey which was conducted more extensively around the area.

The zooplankton samples were vertically collected from bottom to surface at each station by a KITAHARA's quantitative silk tow net stretched with No. XX-13 MÜLLER's gauze. The diameters of the mouth and largest part of the net are ca. 22.5 cm and ca. 50 cm respectively, and the length is ca. 100 cm. The rough volume of every material was measured with a measuring cylinder by the settling method with 24 hours. For each station the total number and settling volume of zoo- and phytoplankton were calculated in each sample per 1 meter haul vertically. The standard hydrological observations such as temperature and salinity at the superficial layer, transparency and water color were made at each station. The method of treatment in examination of the material is similar to that described in my previous papers of this series.

The writer wishes to express his sincere thanks to the director and staff members of the Kyôto Fisheries Experimental Station at Miyazu for making this survey possible most effectively. This investigation was supported in part by a grant for scientific researches from the Ministry of Education.

1) Contributions from the Seto Marine Biological Laboratory, No. 260.
2) This paper has been to be expected to publish in the special volume of "Bulletin of the Biogeographical Society of Japan" in celebration of Dr. Yaichiro OKADA's sixtieth birthday, but was delayed for publishing.

Hydrological Conditions

The hydrological data obtained during this survey are graphically shown in Figs. 1–6. Miyazu Bay is a small tongue-shaped inlet at the west end of Wakasa Bay facing the Japan Sea. The western and innermost area of the bay is shallow,

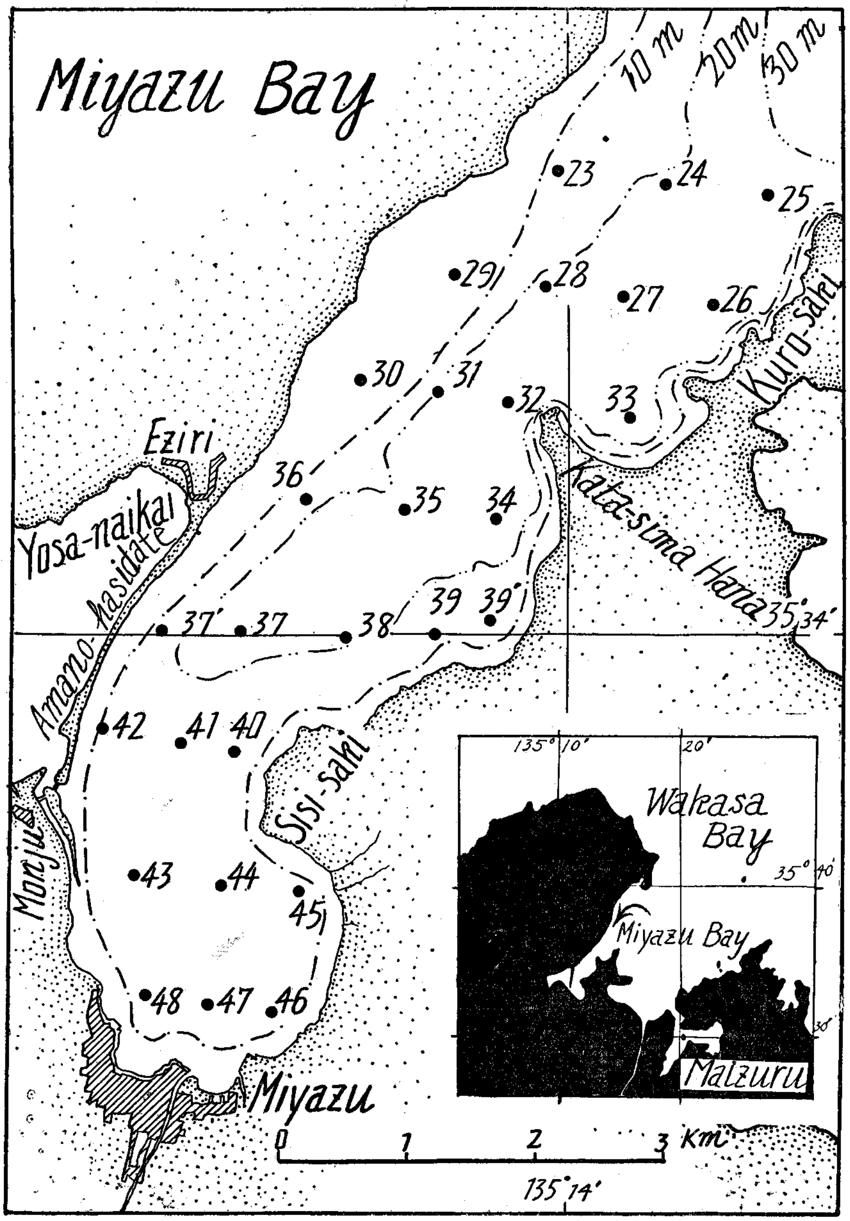

Fig. 1. Chart of Miyazu Bay showing the stations and isobaths.

while the eastern area is deeper than the west. Its basin has steep walls, especially in the northeastern part near the mouth, where the greatest depth reaches 30 m. A small river pours into the inner region at the head of the bay where Miyazu City lies. The western coast of the middle region of the bay forms a sand-bar known as "Amano-hasidate" and the waters of Yosa-naikai located on the west of Amano-hasidate pour into the bay through two small channels, Monju and Kirido. The general oceanographical survey of this bay was made by the Maizuru Marine Observatory (1949, 1952), MIYAZAKI (1952) and HABE & YAMAZI (MS). In the present survey, hydrological conditions such as surface temperature, salinity and catalytic activity of sea water (MATSUDAIRA 1950, YAMAZI 1953), transparency and water color were observed at 28 stations (Nos. 23 to 48) along 8 sectional lines.

The area covered in this survey is small, but, for convenience' sake, may be divided into three regions, the outer, middle and inner, the boundaries between them lying on the parallel lines along the cape Katasima-hana at the north and the cape Sisi-saki at the south.

The surface temperature (Fig. 2) varied from 21.7°C to 24.3°C, being higher in the outer region towards the eastern area of the middle region than in the inner region.

The highest salinity of the surface water was measured at the western part of the mouth, being 32.8 ‰. The salinity decreased from the mouth towards the innermost part along the western shore. The small decrease, on the whole, to the northeast at the equivalent latitudes may suggest the outflow of less-saline water of Yosa-naikai diluted by admixture with river drainage (Fig. 3).

The transparency (Fig. 4) and the water color (Fig. 5) were relatively large in the eastern area of the mouth and showed the gradual decrease towards the western area of the middle region. From the inner region to the eastern area of the middle region, water showed yellowish color and lower transparency.

The distribution of the catalytic activity of sea water is shown in Fig. 6. The values were smaller in the inner region and eastern area of the outer region than in the middle region to the western area of the outer region.

According to the serial oceanographic observations made by the Maizuru Marine Observatory (1949), the current is relatively strong along the western coast than elsewhere and there exists a counterclockwise current. The current is also an important factor of determining the horizontal distribution of plankton in Miyazu Bay.

Plankton

A. Quantitative Analysis of Plankton

The quantity of total plankton in the bay is shown in Fig. 7. The largest volume as well as the densent population of plankton was found in the innermost region and the eastern area of the middle region, lying from off Monju Channel to

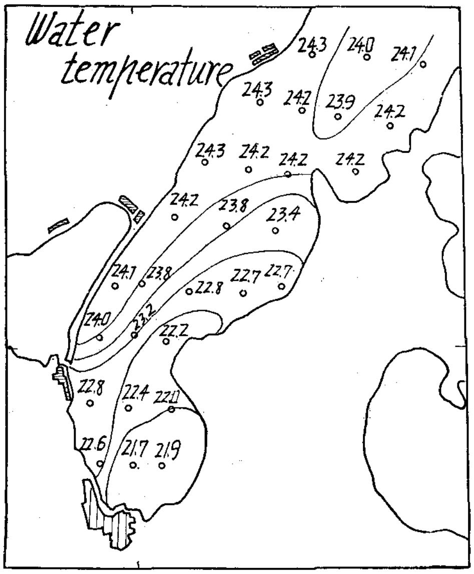

Fig. 2. Distribution of water temperature at the surface.

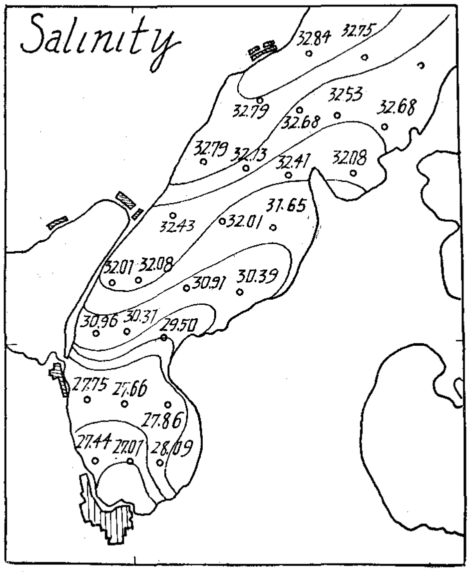

Fig. 3. Distribution of salinity at the surface.

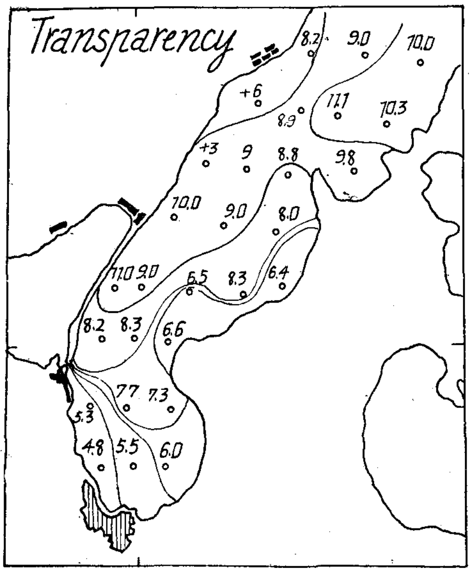

Fig. 4. Distribution of transparency (m).

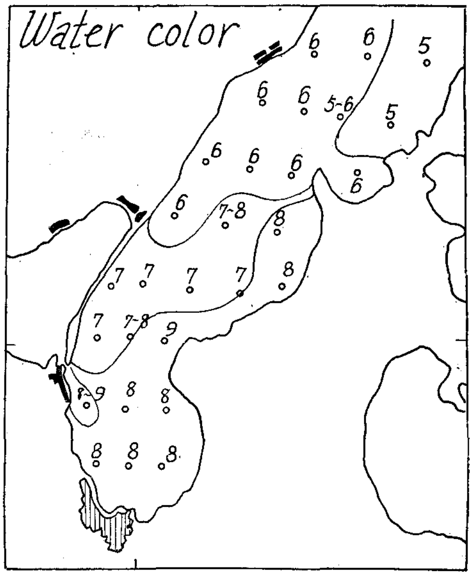

Fig. 5. Distribution of water color (no.)

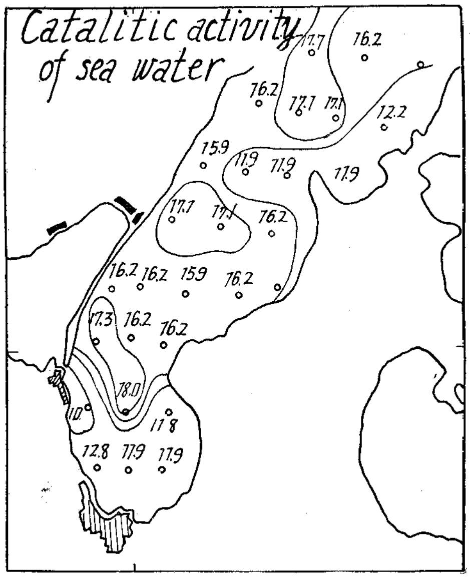

Fig. 6. Distribution of catalytic activity of sea water.

Sisi-saki. The smallest volume or population was obtained from the mouth to Amano-hasidate along the western shore of the bay (Fig. 7, A and B).

The relation between the settling volume and population density is almost the same at all stations (Fig. 8). It shows that the composition or the size of various plankton is nearly similar at all stations. At several stations (Sts. 42, 39, 38, 37 and 48), however, it is not close. This may be due to the richness of phytoplankton composition at different stations.

The zooplankton population (Fig. 9, A) was found densest in the innermost part and the eastern area of the bay, where 3-4 thousands of individuals were counted per 1 meter haul. It generally decreased

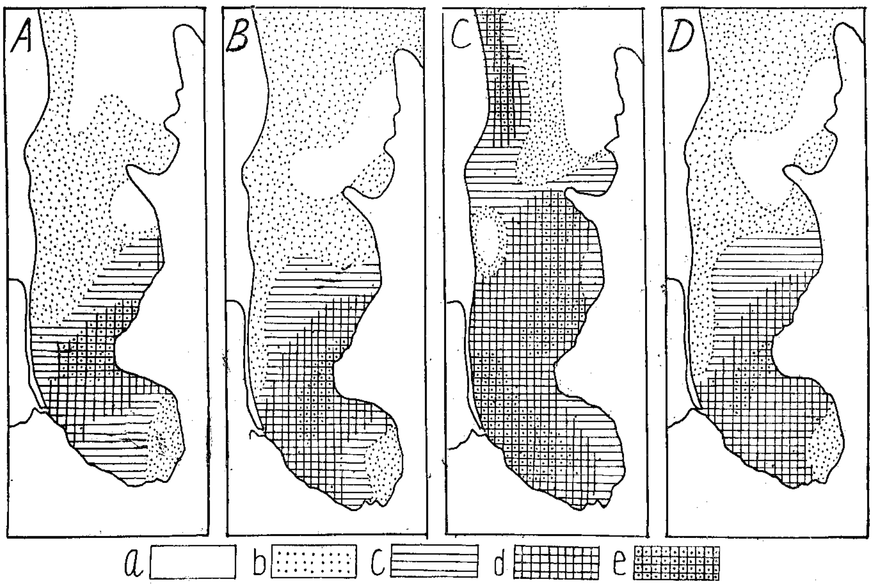

Fig. 7. A: Volume of plankton taken in vertical hauls. Number represents the cubic centimeters taken per 1 meter haul. Contour interval a, <0.1; b, 0.1-0.2; c, 0.2-0.4; d, 0.4-0.5; e, $0.5>$ cubic centimeters.
B: The distribution of the total number of plankton in vertical hauls. Number represents the cubic centimeters taken per 1 meter haul. Contour interval a, 15-16; b, 16-30; c, 30-60; d, 60-100; e, >100 individuals, cells or colonies (Unit of thousand).
C: Distribution of the total number of zooplankton per 1 meter tow. a, 500-1,000; b, 1,000-1,500; c, 1,500-2,000; d, 2,000-3,000; e, $>3,000$.
D: Distribution of total number of phytoplankton per 1 meter tow. a, 14-16; b, 16-30; c, 30-60; d, 60-100; e, >100 (Unit of thousand).

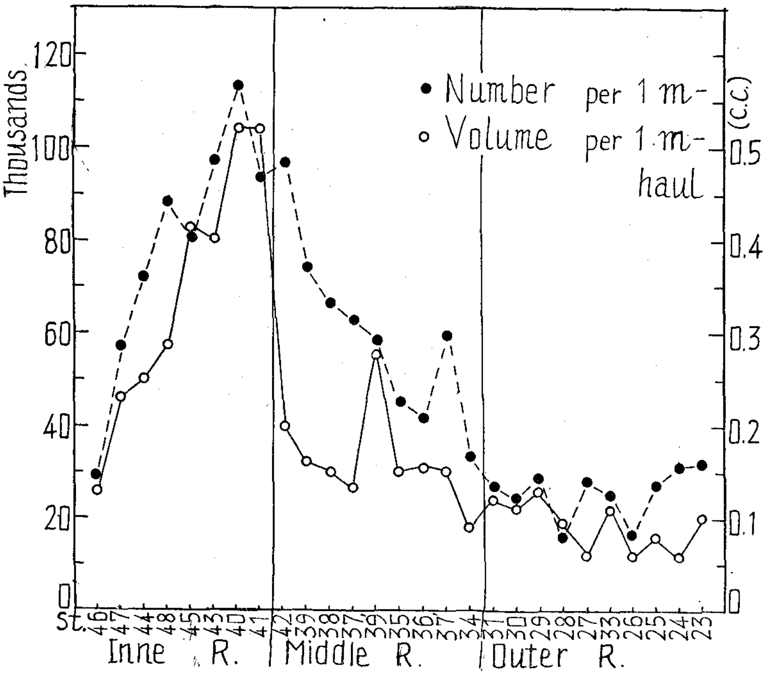

Fig. 8. The relation between the settling volume and the number of individuals, cells or colonies (each per 1 meter haul).

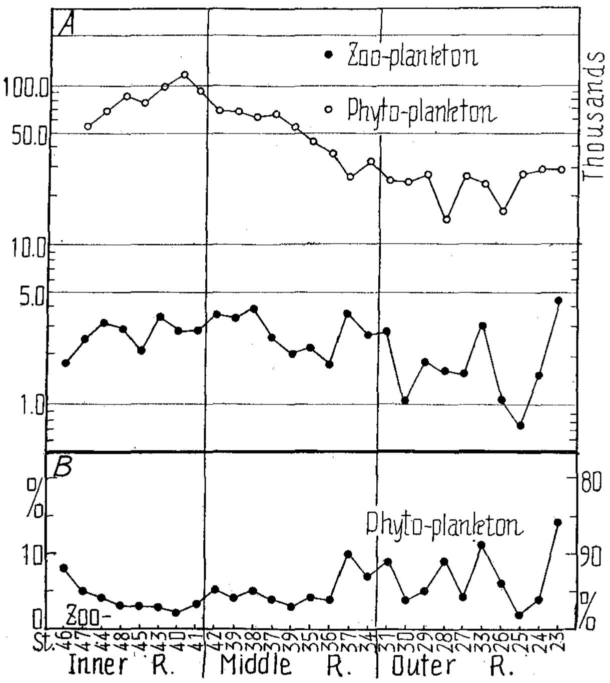

Fig. 9. A: The population of zoo- and phytoplankton per 1 meter haul. B: Percentage composition of zoo- and phytoplankton in the total plankton.

towards the western area and attained the minimum in the eastern part of the entrance. The distribution of phytoplankton (Fig. 9, A) is also in agreement. The numerical percentage of zooplankton to the total plankton (Fig. 9, B) was relatively large, 3–4 % in the inner region and 5–9 % in the outer region of the bay.

B. Qualitative Analysis of Plankton

ZOOPLANKTON :

As in other bays hitherto surveyed, the main component of zooplankton was copepod, its percentage being 60–90% of the total zooplankton, totally about 55 in species (Fig. 10). Next came the larval forms of various animals, such as polychaetes, molluscs, echinoderms and copepods, by 5–35%. The other animal groups, such as chaetognaths, tunicates, doliolids and ostracods were very few and constituted only less than 1% of the animal groups.

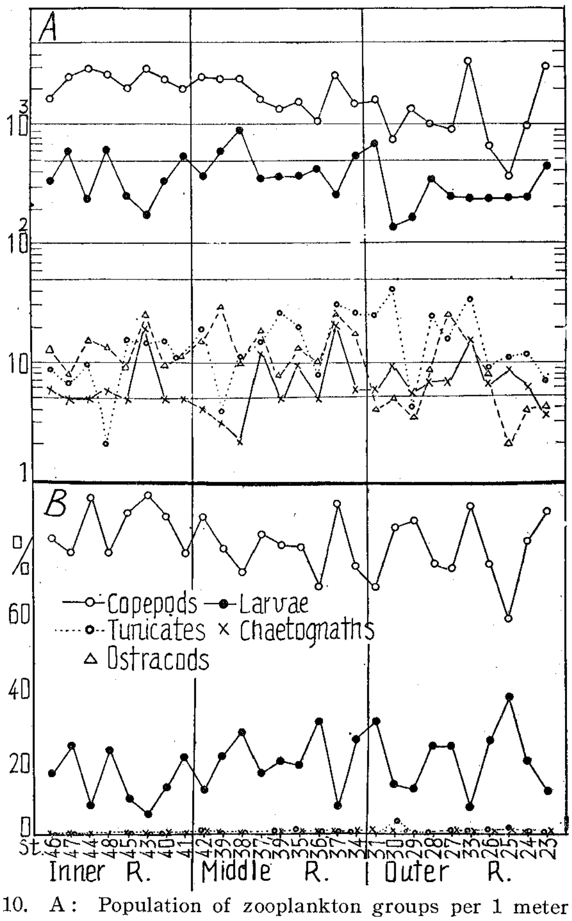

Fig. 10. A: Population of zooplankton groups per 1 meter haul.
B: The percentage composition of their groups.

Copepods: The copepods constitute the predominant group among the zooplankton. Fig. 11 shows the number and percentage composition of their important species. The component of copepods varied according to stations. *Acartia spinicauda* occurred in adundance from the innermost part to the western area of the central region, but not in the outer region of the bay, except near the western coast of the mouth where the water was somewhat slack (Fig. 12, A). *Oithona nana* was the most abundant and occupied 35–70% of the total number of copepods in the innermost part of the bay with peak number at Sts. 43 and 44, while it was very poor in the western area of the middle region and eastern area near the mouth (Fig. 12, B). The next important copepod, *Paracalanus parvus* was widely distributed in the bay, but was the most abundant in the inner region towards the eastern coast and relatively in the

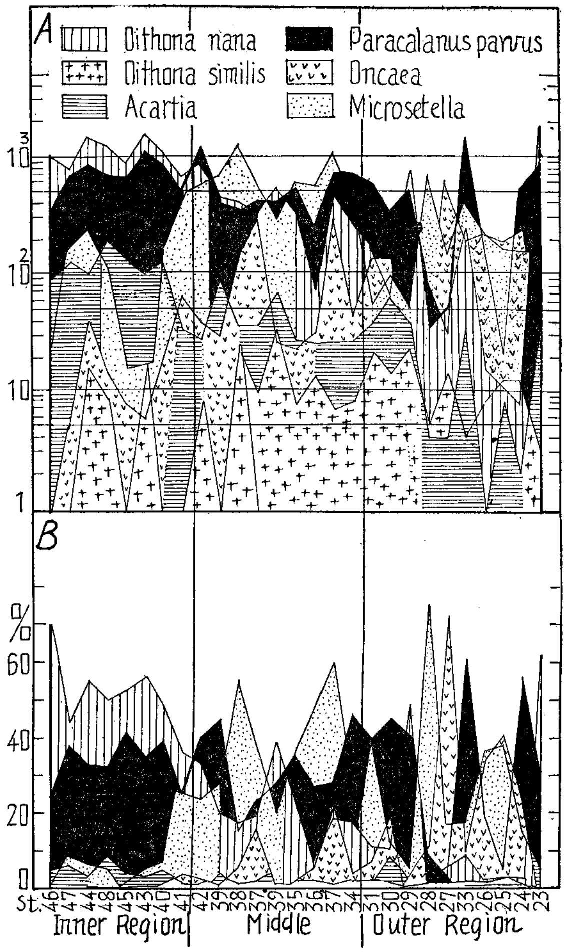

Fig. 11. Number of important copepods (A), and their percentage composition (B).

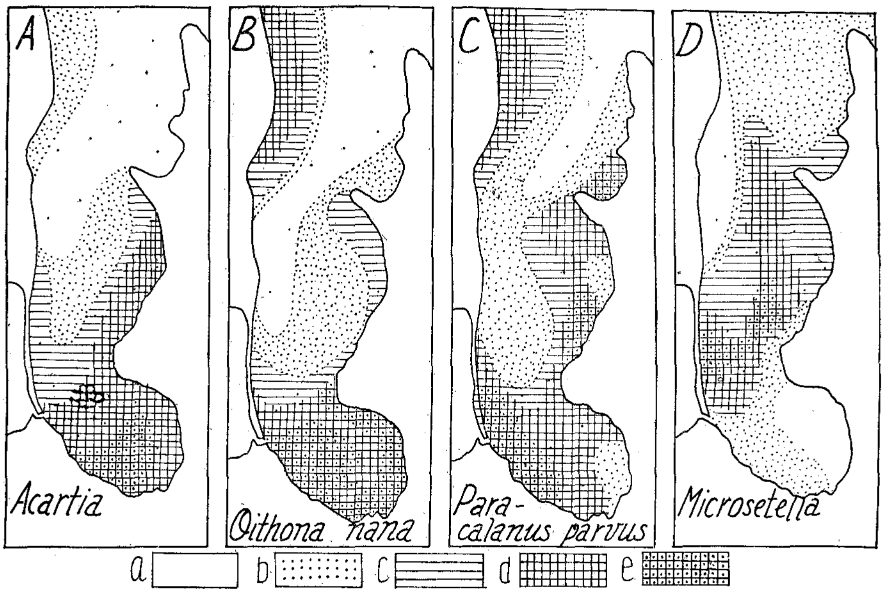

Fig. 12. Showing the distribution of the number of individuals of important copepods (each per 1 meter haul).

A : *Acartia spinicauda* a, $<$10 ; b, 10-20 ; c, 20-50 ; d, 50-100 ; e, $>$100
B : *Oithona nana* a, $<$100 ; b, 100-500 ; c, 500-700 ; d, 700-1,000 ; e, $>$1,000
C : *Paracalanus parvus* a, $<$100 ; b, 100-500 ; c, 500-700 ; d, 700-1,000 ; e, $>$1,000
D : *Microsetella rosea* a, $<$100 ; b, 100-300 ; c, 300-500 ; d, 500-1,000 ; e, $>$1,000

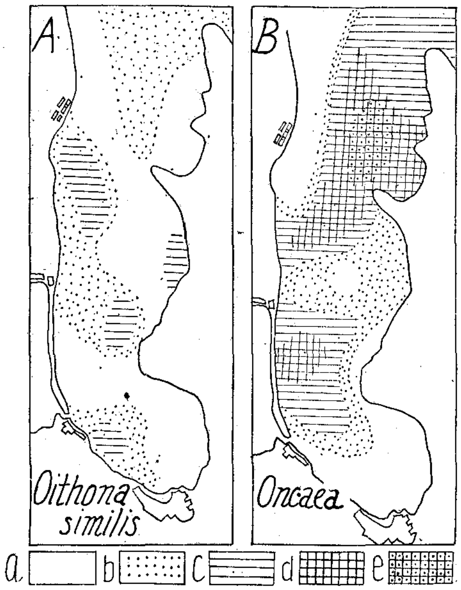

Fig. 13. Showing the distribution of the number of individuals of important copepods (each per 1 meter haul).

A: *Oithona similis* a, $<$10 ; b, 10-20 ; c, 20-30
B: *Oncaea venusta* a, $<$10 ; b, 10-50 ; c, 50-100 ; d, 100-500 ; e, $>$500

western area of the mouth, where dominated by *Oithona nana* (Fig. 12, C). Its percentage was 40–60% in the outside of the middle region except in the west, and about 40% in the innermost part of the bay. This copepods was generally found in abundance in the outer region where *Oithona nana* occurred sparsely (Fig. 12, B & C). It decreased from the eastern area of the mouth towards the western area of the mouth towards the western area of the middle region of the bay. *Microsetella rosea* was found in abundance in the central area and decreased towards the inner and outer region of the bay, and was absent in both the innermost part and western area of the outer region (Fig. 12, D). *Oithona similis* was widely distributed in the bay in a small number, but richly represented in the outer region. *Oncaea venusta* and several other species of *Oncaea* were found from the middle to the outer region of the bay and the richest in the eastern area (Fig. 13, A & B). Other copepods which appeared sparsely in the bay and brought into the bay from Wakasa Bay are listed as follows:

Species	Outer region	Inner region
Calanus darwinii	+	—
Calanus tenuicornis	+	—
Eucalanus attenuatus	+	—
Acrocalanus longicornis	+	—
Tortanus forcipatus	+	—
Temora herdmanii	+	—
Oithona plumifera	+	—
Oithona rigida	+	+
Candacia sp.	+	—
Euterpe acutifrons	+	+
Corycaeus sp.	+	—
Centropages sp.	+	+
Paracalanus aculeatus	+	—

Other animals: Of the Cladocera, *Evadne tergestina*, *Penilia schmackeri* and *Podon* sp. appeared widely but in small numbers. A small number of appendicularians represented by *Oikopleura dioica*, *O. longicauda* and *Fritillaria haplostoma* were found. The first one was widely distributed, but the other two were found chiefly in the mouth towards the western area as *Doliolum nationalis* was. The hydromedusae, such as *Solmaris*, *Liriope* and *Aglaura* were not found in the bay though scarce outside the bay. The chaetognaths were represented only by *Sagitta enflata* and *S. crassa* f. *naikaiensis*. The former species was found in a small number in the outer region of the bay, but the latter widely in all areas of the bay in a small number. Protozoans were represented mostly by the Tintinnoinea, of which *Favella campanula*, *Favella ehrenbergii*, *Tintinnopsis radix*, *Tin. beroidea* and *Helicostomella longa* were sparsely observed. The others were *Noctiluca* and several species of radiolarians.

Larval forms: The main components of larval forms were the nauplii of copepods such as *Oithona* and *Paracalanus*, which were found richer in the inner region and the eastern area than in the outer region and the western area of the middle region. The molluscan veligers, polychaete larvae, ophioplutei, auricularia, bipinnaria, echinoplutei, Müller's larvae and nauplii of 5 species of Crustacea were also found.

PHYTOPLANKTON:

About 70 important species of phytoplankton were identified. The main component was as usual the *Chaetoceros* group, which appeared predominantly in the inner region and occupied about 20–65% of the total phytoplankton. Among this group, the following *Chaetoceros* species were significant:

Species	Outer region		Middle region		Inner region
	Westward	Eastward	Westward	Eastward	
Ch. coarctatus	r	r	rr	rr	–
Ch. Eibenii	rr	rr	rr	–	–
Ch. tetrastichon	–	rr	rr	–	–
Ch. peruvianus	r	r	r	r	rr
Ch. pacificus var. *neapolitana*	rr	rr	rr	–	–
Ch. decipiens	r	r	r	r	rr
Ch. Lorenzianus	rr	rr	rr	r	r
Ch. didymus	cc	cc	cc	ccc	ccc
Ch. affinis	r	c	r	r	r
Ch. laciniosus	c	c	cc	cc	cc
Ch. laevis	r	c	c	r	rr
Ch. compressus	r	r	r	r	r
Ch. paradoxum	rr	rr	rr	rr	–

Thalassiothrix Frauenfeldii and *Thalassionema nitzschioides* came next in numerical importance and were distributed chiefly in the inner region (Figs. 14 & 15). *Biddulphia longicruris* was also important and showed a similar tendency in distribution to that of *Chaetoceros laciniosus* and *Thal. Frauenfeldii*. The other species such as *Bidd. sinensis* were widely distributed but in small numbers.

The *Rhizosolenia* group, on the other hand, was rich in the outer region than in the inner. *Rh. hebetata* f. *semispina*, *Rh. alata* f. *gracillima*, *Rh. imbricata* var. *shrubsolei* and *Rh. calcar avis* were numerous in the outer region and the western area of the middle region. *Rh. Bergonii*, *Rh. Stolterfothii*, *Rh. robusta*, *Rh. setigera*, *Rh. alata* f. *indica* and *Rh. acuminata* were also found, showing a similar distribution.

Other important diatoms were the species, such as *Stephanopyxis palmeriana*, *Leptocylindrus danicus*, *Dactyliosolen antarcticus*, *Guinardia flaccida*, *Cos. excentricus*, *Cos. Granii*, *Cos.* sp., *Hemiaulus Hauckii*, *Climacodium biconcavum*, *Clim. Frauenfeldianum* and *Ditylum sol.*

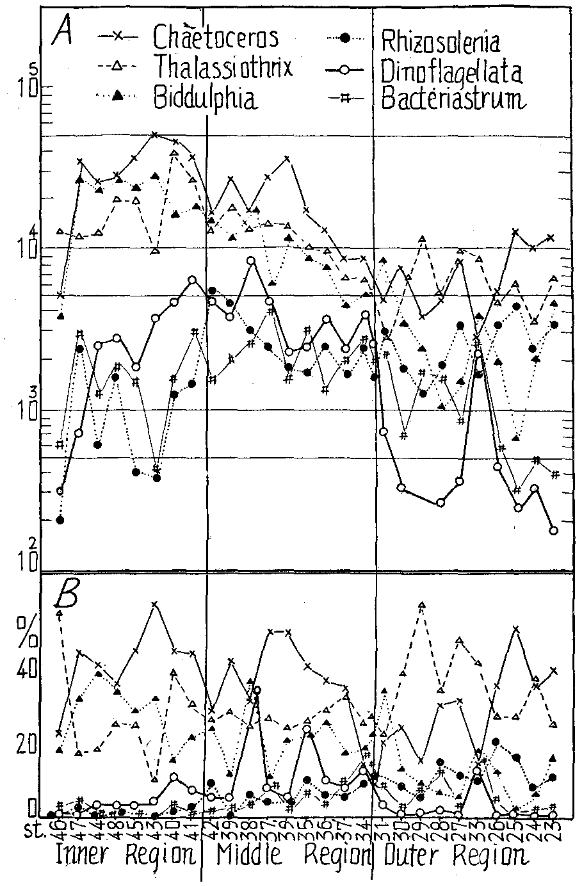

Fig. 14. Cell or colony number (A) and percentage composition (B) of important phytoplankton.

Dinoflagellates were rather unevenly distributed in the bay. Among them, *Cer. fusus*, *Cer. furca*, *Cer. pennatum*, *Cer. tripos*, *Cer. trichoceros* occurred rather abundantly and were the richest in the middle region. The other species such as oceanic forms *Cer. macroceros*, *Cer. carriense*, *Cer. palmatum*, *Cer, candelabrum*, *Cer. berone*, *Ceratocoris horrida*, *Pyrophacus horologicum*, *P. hamulus* var. *inaequalis*, *Pyrocystis noctiluca*, *Amphisolenia bidentata*, *Dinophysis homunculus* and *Peridinium grande* were scarcely found in the outer region and the western area of the mindle region. These species may be immigrants from the Wakasa Bay. *Prorocentrum micans* and *Per. oceanicum* var. *oblongum* were evenly distributed in small numbers.

Discussion

General Consideration on Regional Distribution

Although Miyazu Bay is a narrow inlet forming a branch of Wakasa Bay on the

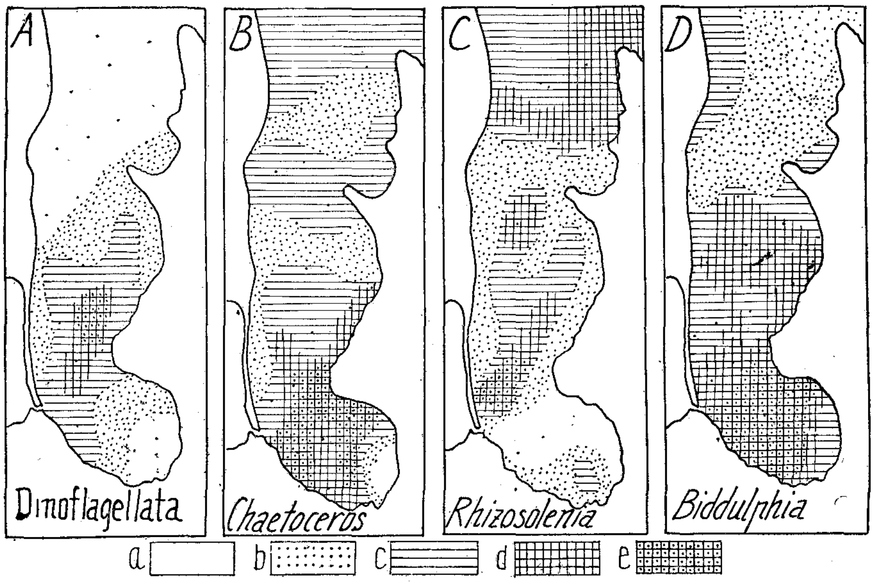

Fig. 15. Distribution of important phytoplankton groups (each per 1 meter haul).
A: Dinoflagellata a, <500 ; b, 500–1,000; c, 1,000–4,000 ; d, 4,000–8,000 ; e, >8,000.
B: *Chaetoceros* a, 1,000–5,000; b, 5,000–10,000; c, 10,000–20,000; d, 20,000–30,000; e, >30,000.
C: *Rhizosolenia* a, <1,000; b, 1,000–2,000; c, 2,000–3,000 ; d, 3,000–4,000 ; e, 4,000–5000.
D: *Biddulphia* a, <3,000; b, 3,000–5,000; c, 5,000–10,000; d, 10,000–20,000; e, 20,000–30,000.

Japan Sea coast and has a simple form especially along the west coast, the hydrological condition of the bay varies greatly between the western, eastern and southern inner areas. The basin of the northern region of the bay is shallower westwards, and the water decreases in salinity eastwards and more conspicuously inwards and clearer along the west coast than on the east. This suggests that the open sea waters of Wakasa Bay flow into this bay along the west coast, and then flows eastwards in the inner region, as mixed with less-saline water from the river drainage. Thus it may be understood that in this bay area exists a weak counterclockwise circulation (Maizuru Oceanographical Observatory, 1949, 1952). Topographical and hydrological conditions exert a directive influence to the distribution of the plankton communities.

As the water movement indicators of this bay the following four species of copepods seem to be the most significant: *Oithona nana*, *Paracalanus parvus*, *Microsetella rosea* and *Oncaea venusta* (Fig. 16).

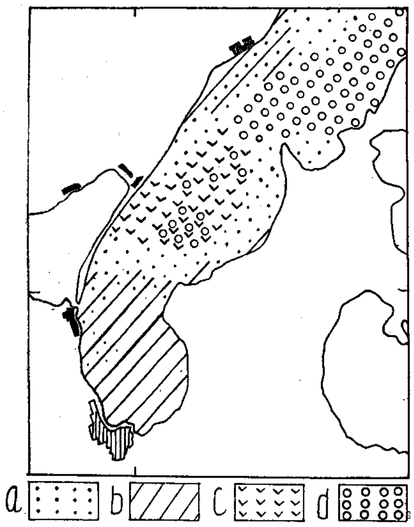

Fig. 16. Distribution of dominant copepods in Miyazu Bay.
a, *Paracalanus parvus*; b, *Oithona nana*; c, *Microsetella rosea*; d, *Oncaea* spp.

1. *Oithona nana* area.

The inner region and the east coast area of the middle region were densely occupied by the small copepod *Oithona nana.* Next *Paracalanus parvus* was also numerous. Its population density was the largest in the inner region, constituting more than 50% of the total copepods. These areas of the bay were thus evidently predominated by *Oithona nana* and *Paracalanus parvus* whose distribution extends far out of the bay. *Acartia spinicauda* was confined to protected waters of the innermost area where polluted with less-saline waters from rivers and the stagnated lagoon, Yosa-naikai. A large number of diatoms such as *Chaetoceros*, *Biddulphia* and *Thalassiothrix* were also abundant, but dinoflagellates and *Rhizosolenia* were rather poor in number and species.

2. *Paracalanus parvus* area.

The area between the inner and middle region to the east coast of the middle region, was dominated by *Paracalanus parvus.* In this area, *Oithona nana*, *Microsetella rosea* and *Oncaea* were also abundant, though not so large as *Paracalanus parvus.* The water in this area is more or less stagnant and more saline than in the innermost region, dominated by *Oithona nana.*

3. *Microsetella rosea* area.

Most of the middle region especially along the shore of Amano-hasidate was occupied by the *Microsetella* community most abundantly. *Oncaea venusta, Oncaea* spp. and *Rhizosolenia* were rather abundant. The offshore animals, diatoms and dino-flagellates were found sparsely. The water of this area is also relatively stagnant but shows higher salinity than in the above-mentioned area.

4. *Oncaea* area.

The eastern area of the outer region was characterized by the predominance of *Oncaea venusta* and *Oncaea* spp. over the other inshore organisms. Several offshore copepods, *Oithona similis*, *Doliolum* sp. and *Fritillaria* sp. were also found at each station, and here their quantity was small but abundant in number of species. The outer region is influenced strongly by the influx of the open waters, with high salinity and transparency, lower class of water color.

Zooplankton and its Relationship to Current

The movement of the water-mass itself may profoundly affect the distribution and population of the plankton, though it is carried with the water when the water-mass moves. The use of plankton as indicators of various water-masses and their movement has been fully discussed by many workers in the English Channel (RUSSELL, 1935, 1936), Gulf of Maine (REDFIELD and BEALE, 1940; REDFIELD, 1941) and Sea of Japan (YAMAZI, 1953).

According to the oceanographical observations sometimes made by the MAIZURU MARINE OBSERVATORY (1949, 1952, 1952 a) in Miyazu Bay, there is a weak counter-clockwise circulation within the bay in respect to the surface current or non-tidal drift. This circulation is augumented by the inflow of the open sea water along the western shore across the area off the cape Kuro-saki. The inflow is relatively barren in oceanic plankton and does not provide good conditions for development and reproduction of plankton till mixing with the more sheltered waters. The plankton animals are thus crowded together in relatively quiescent waters of the inner region of the bay, where both *Oithona nana* and *Paracalanus parvus* are dominant. Their dense population in the southwestern area of the inner region extended northeastward to the cape Katasima-hana along the east coast, and thereabout a part may be caught in the recurrent drift near Sts. 34, 32 and 35, and carried again southward in the inner part of the bay (Figs. 7, 12 and 13).

It is evident that the distribution of plankton population indicates the water movement of the bay. In conclusion it should be pointed out that some of the important littoral copepods can be used not only as indicators of water movement in solving some of hydrographic problems but also to help in understanding the very complex minor factors affecting the biomass, even in such a restricted or small area as the inlet waters, as done by most of the earlier workers in the offshore waters.

Summary

1. On September 29th, 1950, the second survey was made in Miyazu Bay to study the plankton community in relation to the water movement. The hydrological data and the fluctuations of the plankton communities obtained quantitatively and qualitatively were described.

2. The variation of the plankton distribution was closely correlated with the circulation, deduced from the hydrological and planktological observations.

3. The regional distribution of plankton was discussed. On the basis of the regional abundance of some important copepods, Miyazu Bay can be divided into four ecological areas dominated by: (1) *Oithona nana*, (2) *Paracalanus parvus*, (3) *Microsetella rosea* and (4) *Oncaea*, respectively.

4. The principal factor affecting the quantitative and qualitative distribution of zoo- and phytoplankton is a complex between the inflow of relatively barren open sea water and the outflow of fertile bay water.

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