PLANKTON INVESTIGATION IN INLET WATERS ALONG THE COAST OF JAPAN

IV. THE PLANKTON OF NAGASAKI BAY AND NAGASAKI HARBOUR IN KYUSYU*

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With 8 Text-figures and 1 Table

The present paper deals with the result of survey made in Nagasaki Bay on July 14, 1949. The methods of survey and examining the material are the same as those described in previous papers of this series (YAMAZI, 1950, 1951, 1952). The writer wishes to express his hearty thanks to the members of the Nagasaki Marine Observatory for their kind help offered him during the field work. This work was also made possible by a grant from the expenditure for scientific research of the Ministry of Education.

For details of general oceanographical conditions of the bay, the reader in referred to mimeographed reports published by the Nagasaki Marine Observatory.**

Hydrological Coditions

Nagasaki Bay is situated on the western coast of Kyusyu, and about 40 miles south of Imari Bay mentioned in the preceding report. It opens southwestwards to the East China Sea (Fig. 1). Nagasaki Harbour, which is well known as one of the old commercial ports in Japan, occupies the inmost part of the bay and is roughly spatulate in outline. The harbour and the bay are connected with a narrow neck about 600 m across. Several streams, such as Uragami-gawa, Iwahara-gawa and Nakasima-gawa flow into the harbour,

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** YASUI, Z. et al., 1948. Report of the second oceanographical investigation of Nagasaki Harbour. Kaikyo Ryakuhō, no. 4, pp. 7–14. (in Japanese).
YASUI, Z. & YAMANO, S. 1947. Tidal currents in Nagasaki Harbour. Oceanography & Meteorology, vol. 1, no. 5. pp. 14–16. (in Japanese).

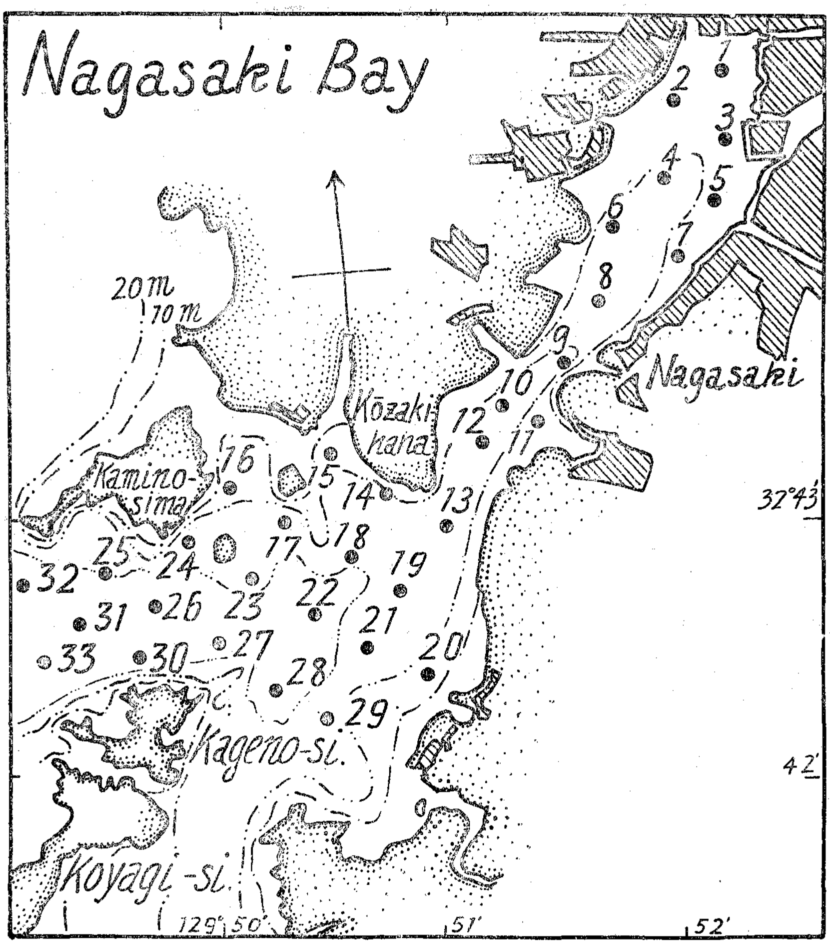

Fig. 1. Map of Nagasaki Bay showing stations and isobaths.

passing through the city of Nagasaki. The harbour is thus relatively shallow, showing the depth of about 7–16 meters. The southwestern part of the harbour is deeper, measuring about 20–30 meters in its center. The bay is guarded from the influences of the open sea by several island, such as Takahoko-sima, Nezumi-sima, Kamino-sima, Kageno-sima, and Kōyagi-sima. Owing to the inflow of the sewage, the water of the harbour shows small transparency, yellowish brown color and lower salinity in wide areas.

Water temperature (Fig. 2, A and B) : The surface temperature ranged from 23.6° to 25°C, being lower near the mouth than in the northern part of the bay as well as in the harbour. In the 5 m layer, it was 22.7°–23.6°C, and a little higher in the mouth of the bay (about 22.3°–23.6°C) than in the har-

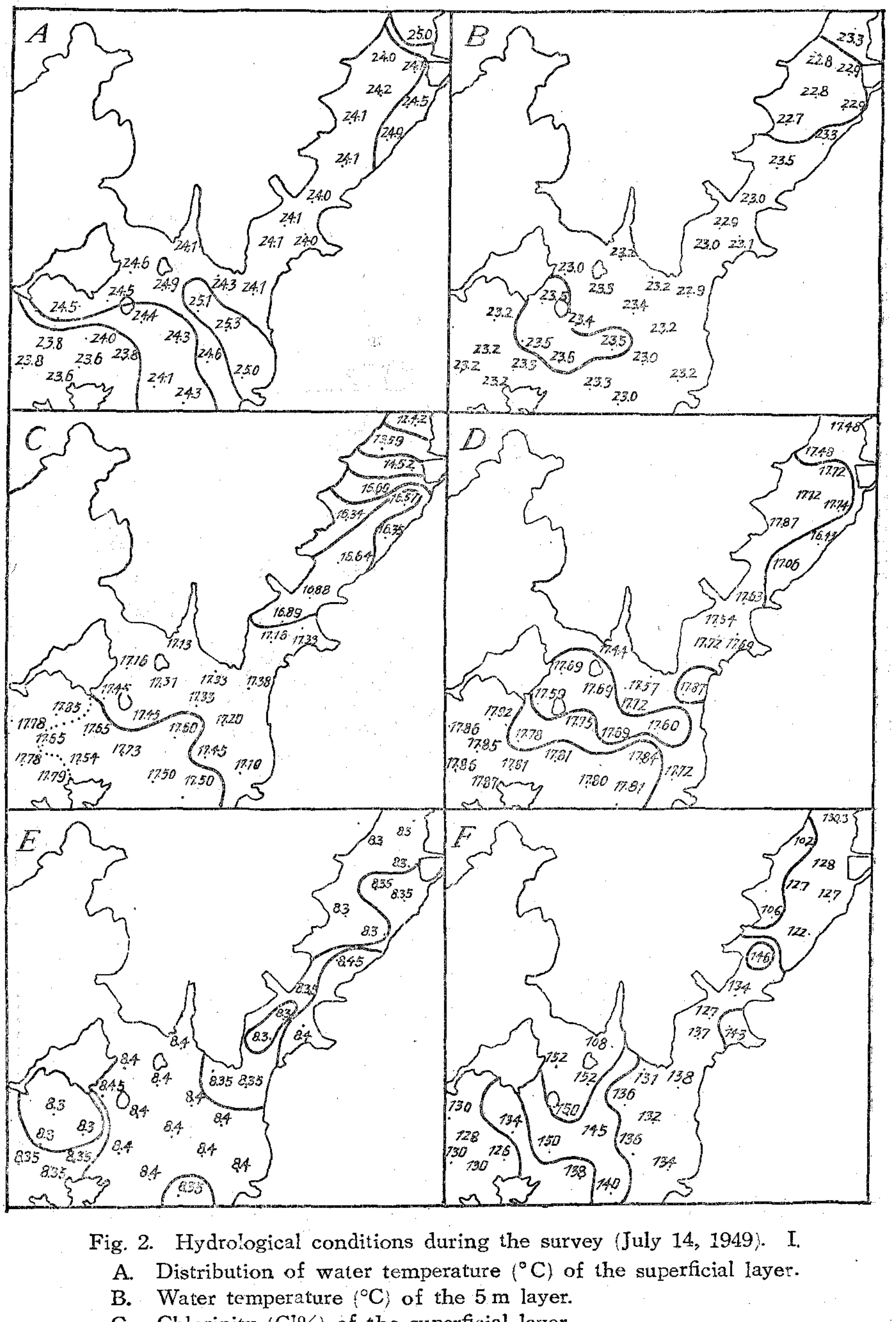

Fig. 2. Hydrological conditions during the survey (July 14, 1949). I.

A. Distribution of water temperature (°C) of the superficial layer.
B. Water temperature (°C) of the 5 m layer.
C. Chlorinity (Cl‰) of the superficial layer.
D. Chlorinity (Cl‰) of the 5 m layer.
E. pH value of the 5 m layer.
F. Saturation degree of oxygen of the 5 m layer.

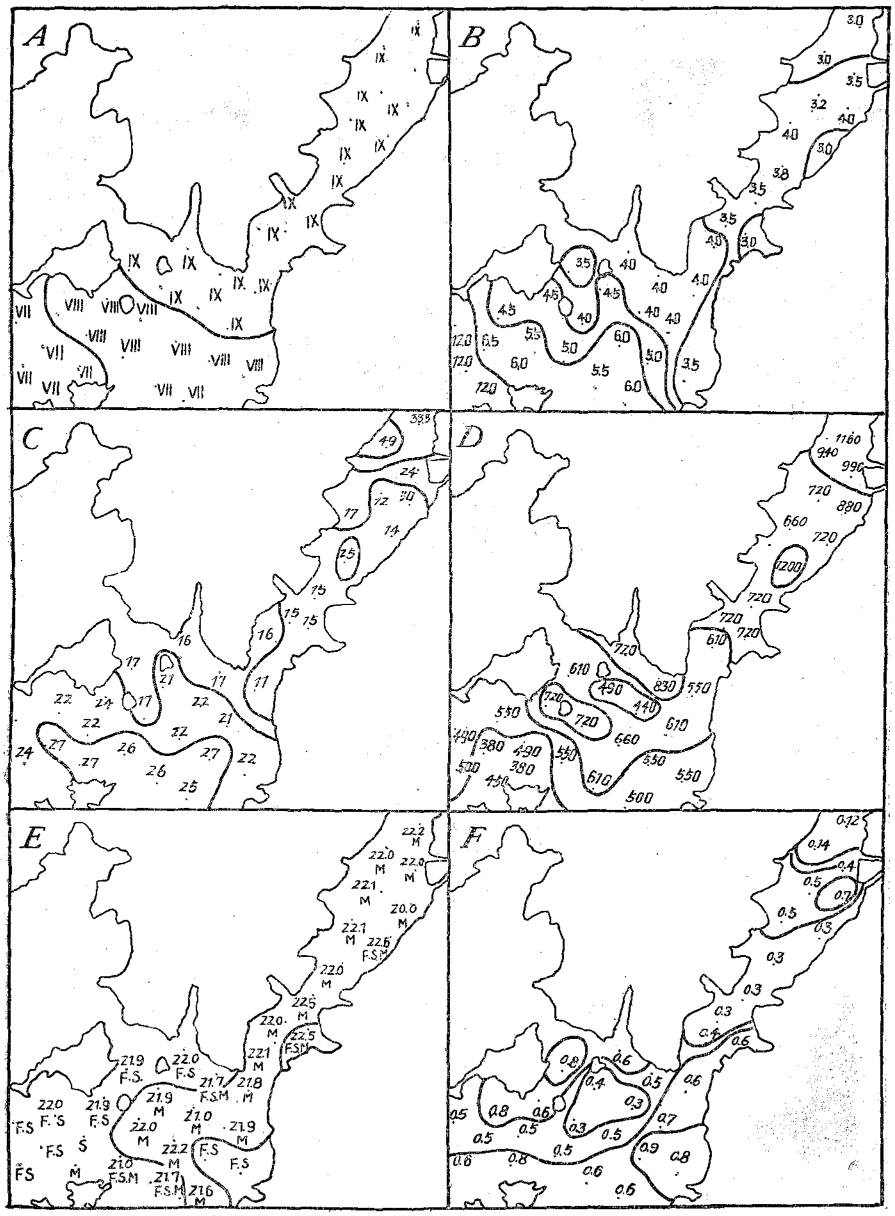

Fig. 3. Hydrological conditions during the survey (July 14, 1949). II.
A. Distribution of water color.
B. Distribution of transparency.
C. Distribution of phosphates (P_2O_5 mg/m^3) of the 5 m layer.
D. Distributiou of silicates (SiO_2 mg/m^3) of the 5 m layer.
E. Mud temperature and texture of ground.
F. Settling volume (cc) of plankton per 10 liters between surface and bottom.

bour (about 22.7°–23.0°C). The temperature of the bay was thus higher than that of the Imari Bay at equivalent levels, especially in the 5 m layer.

Chlorinity (Fig. 2, C and D): The chlorinity of the surface water of the bay was 17.1–17.8 Cl ‰ near the mouth and in the central part of the bay, and 12.4–16.9 Cl ‰ in the inner part of the harbour. The chlorinity of the 5 m layer was higher, measuring 17.6–17.9 Cl ‰ near the mouth and in the central part of the bay, and 17–17.6 Cl ‰ in the harbour.

pH value and dissolved oxygen content: The pH value of the 5 m layer is shown in Fig. 2, E. It was very large and constant, being about 8.3–8.4 at almost all stations, but a little lower in the innermost part of the harbour than elsewhere. The dissolved oxygen content of the 5 m layer was smaller in the innermost part than in the mouth of the harbour as well as in the bay (Fig. 2, F). Owing to the abundance of the photosynthetic plankton, the saturation degree of oxygen was very large (120–150 %), excepting a small area of the innermost part of the harbour.

Transparency and water color (Fig. 3, A and B): The transparency of the water was the smallest in the inner part of the harbour, measuring about 3–3.5 m. Owing to strongly polluted water from its surrounding city, the harbour water was very turbid, showing no. 9 of FOREL's scale. The water towards the central and the mouth parts of the bay became more transparent, measuring about 4–6 m and attained about 12 m near the mouth, where the water color was yellowish-green (no. 7 of FOREL's scale).

Phosphates (P_2O_5) *and silicates* (SiO_2): The phosphates and silicates contents of the 5 m layer are shown in Fig. 3, C and D. They varied between 10 and 50 mg/m^3 and from 400 to 1200 mg/m^3 respectively. These values are comparatively lower than those measured in Imari Bay. P_2O_5 as well as SiO_2 contents were smaller in the central part of the bay (11–20 mg/m^3 of P_2O_5; 450–800 mg/m^3 of SiO_2) and in the mouth (22–27 mg/m^3 of P_2O_5; 380–550 mg/m^3 of SiO_2).

The mud temperature and the texture of bottom samples are shown in Fig. 3, E.

Plankton

A. Quantitative Analysis of Plankton

The plankton samples were hauled at 32 stations (Fig. 1). The settling volume of plankton (Fig. 3, F) was much larger in the bay than in the harbour. It was 0.6–0.9 cc per 10 liters in the northern and southern part of the bay, 0.3–0.4 cc in the central and 0.5–0.8 cc near the mouth. It was found smallest in the innermost part of the harbour. Owing chiefly to the richness of diatoms, the volume of plankton was much larger in this bay than in Imari Bay (YAMAZI, 1952).

The plankton population was very large throughout all stations. The largest number obtained was 280 thousands per 10 liters at St. 1 and 4; 5 stations had the population larger than 200 thousands; 7 stations 150–200 thousands; 18 stations 100–150 thousands.

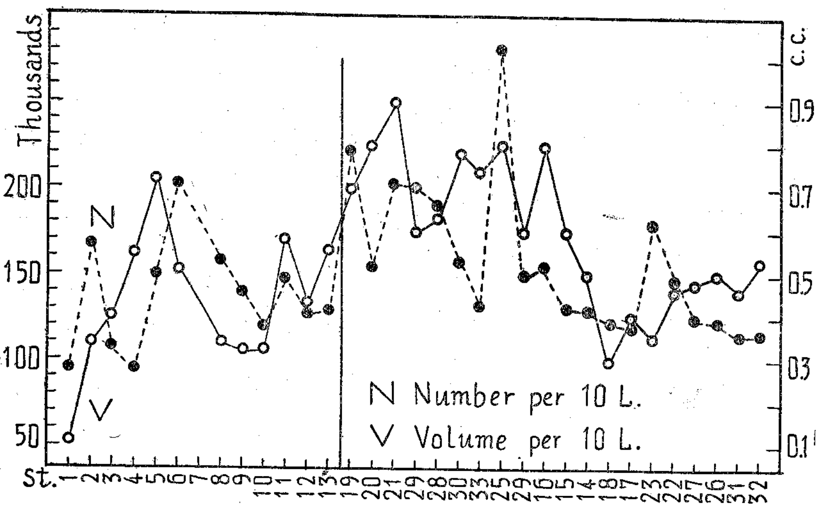

Fig. 4. Relation between settling volume (cc) of plankton and the number of individuals, cells or colonies (each per 10 liters.)

As is shown in Fig. 4, B, the relation between the settling volume of plankton and the total number of individuals, cells or colonies is never parallel. This fact implies the presence of remarkable variations in the plankton composition of different parts of the bay.

The population of zooplankton was found densest in the innermost part of the harbour and in the northern part of the bay, where the number of zooplankton reached 600–1800 per 10 liters, but it was much smaller in the mouth and the central part of the bay. The numerical percentage of zooplankton in the total plankton ($Z/N \times 100$) was very small, less than 0.3% in the mouth of the bay, and generally increased towards the innermost part of the harbour (about 1.1 %) (Fig. 5, A).

The phytoplankton was the densest in the northern and southern parts of the bay as well as in the central part of the harbour, where 150–280 thousands of cells or colonies were found. It was the thinnest in the aggitated area near the mouth of the bay and also in the polluted area in the innermost part of the harbour. The numerical percentage of phytoplankton in the total plankton (P/N×100) appeared quite large in the mouth (more than 99.7 %) of the bay and decreased towards the inner region and attained 98.9 % in the innermost part of the harbour.

The bay as well as the harbour is thus characterized by the rich productivity of diatoms in wide areas (from the innermost part of the harbour to the mouth of the bay).

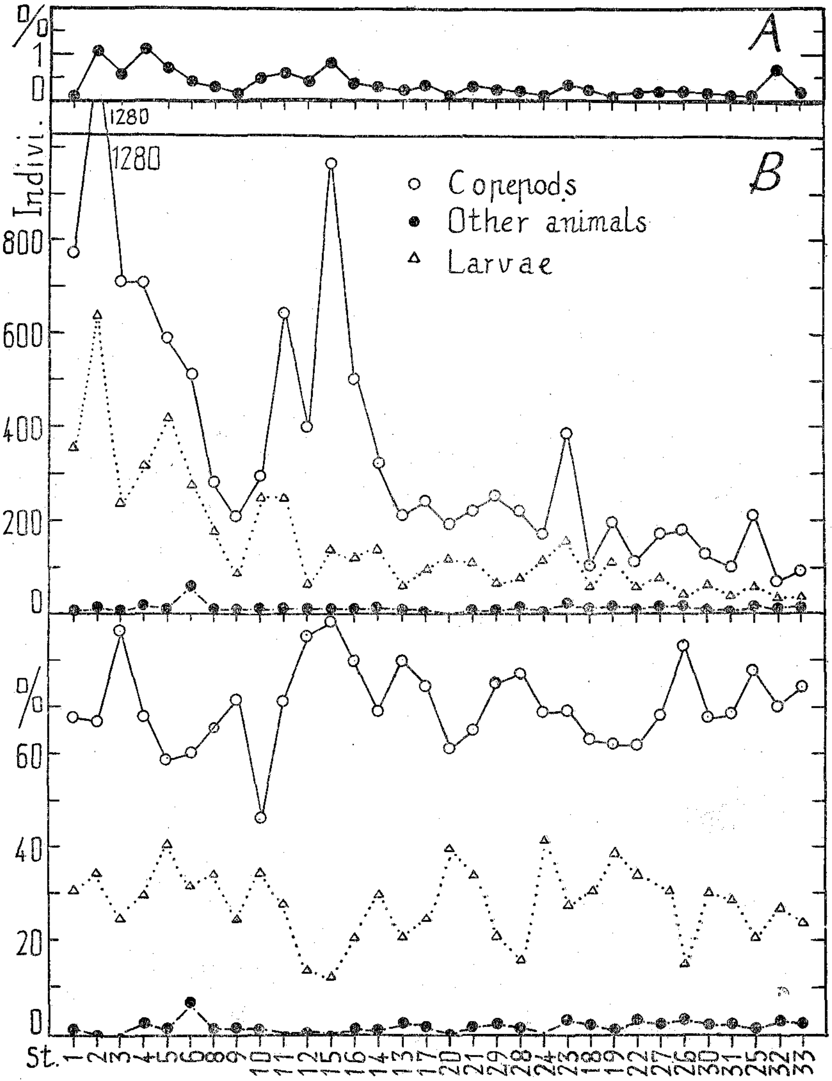

Fig. 5. A. Ratio between zoo- and phytoplankton.
B. Population of zooplankton groups per 10 liters (above) and their percentage composition (below).

B. Qualitative Analysis of Plankton

Zooplankton: As is shown in Fig. 5, B, the main part of zooplankton of the bay and the harbour, so far as the present investigation concerned, was

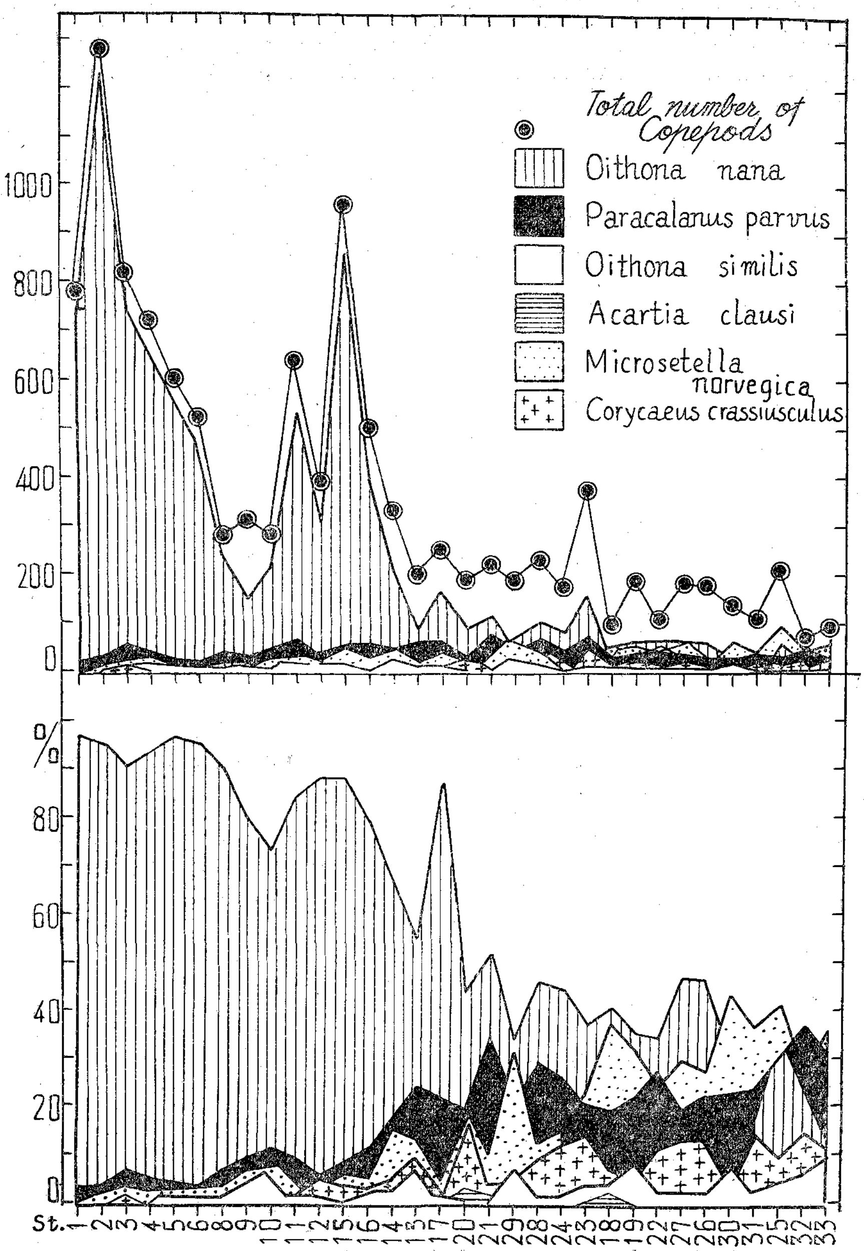

Fig. 6. Number of important copepods per 10 liters between surface and bottom (above) and their percentage composition (below).

occupied by copepods at the frequency of 60-90 %. The other animal groups including Protozoa, Chaetognatha and Copelata were only less than 3 % in the percentage composition. The larval forms, such as nauplii of copepods and cirripeds and veligers of molluscs, were represented by 15-40 % in total zooplankton.

Fig. 6 shows the number and percentage composition of the main species of copepods. As in the case of Imari Bay (The third report of this series), the main components of copepods in this bay and harbour are similar. However, a slight dissimilarity in the percentage composition could be found. *Oithona nana* was predominant and observed most abundantly in the innermost part of the harbour. Its percentage reached more than 80 % at the interior of the harbour and in the northern part of the bay, but decreased gradually outwards, and attained the minimum at the mouth of the bay (15-23 %). *Paracalanns parvus* and *Microsetella norvegica* were evenly distributed in the bay in moderate numbers, though the percentage of both species increased gradually outwards, from the inner part of the harbour (3-5 %) to the mouth of the bay (35-40%). *Oithona nana* and *Corycaeus crassiusculus* showed a rather uneven distribution at the frequency of 1-9 % ; they were more abundant in the bay than in the harbour, except in the innermost part of the harbour, where they were absent. No oceanic copepod was observed during this survey.

Among tintinnoids, *Tintinnopsis radix*, *Tintinnopsis beroidea* and *Tintinnus lusus-undae* were frequent, but very sparsely found in the harbour. The typical inshore chaetognaths *Sagitta delicata* and *S. crassa* forma *naikaiensis* were widespread in the bay as well as in the harbour, though in small numbers.

The main components of larval forms were the veligers of bivalves and the nauplii and copepodids of *Oithona nana*. They were most abundant in the harbour and the northern area of the bay. Other species found in the samples are listed as follows:

Species	Nagasaki Harbour	Nagasaki Bay
Centropages sp.		+
Euterpe acutifrons	+	+
Oncaea venusta		+
Radiolaria spp.		+
Polychaeta larva	+	+
Nauplii of Cirripedia	+	+
Evadne nordmanni	+	+
Podon sp.	+	+
Penilia schmackeri	+	+
Ophiopluteus	+	+

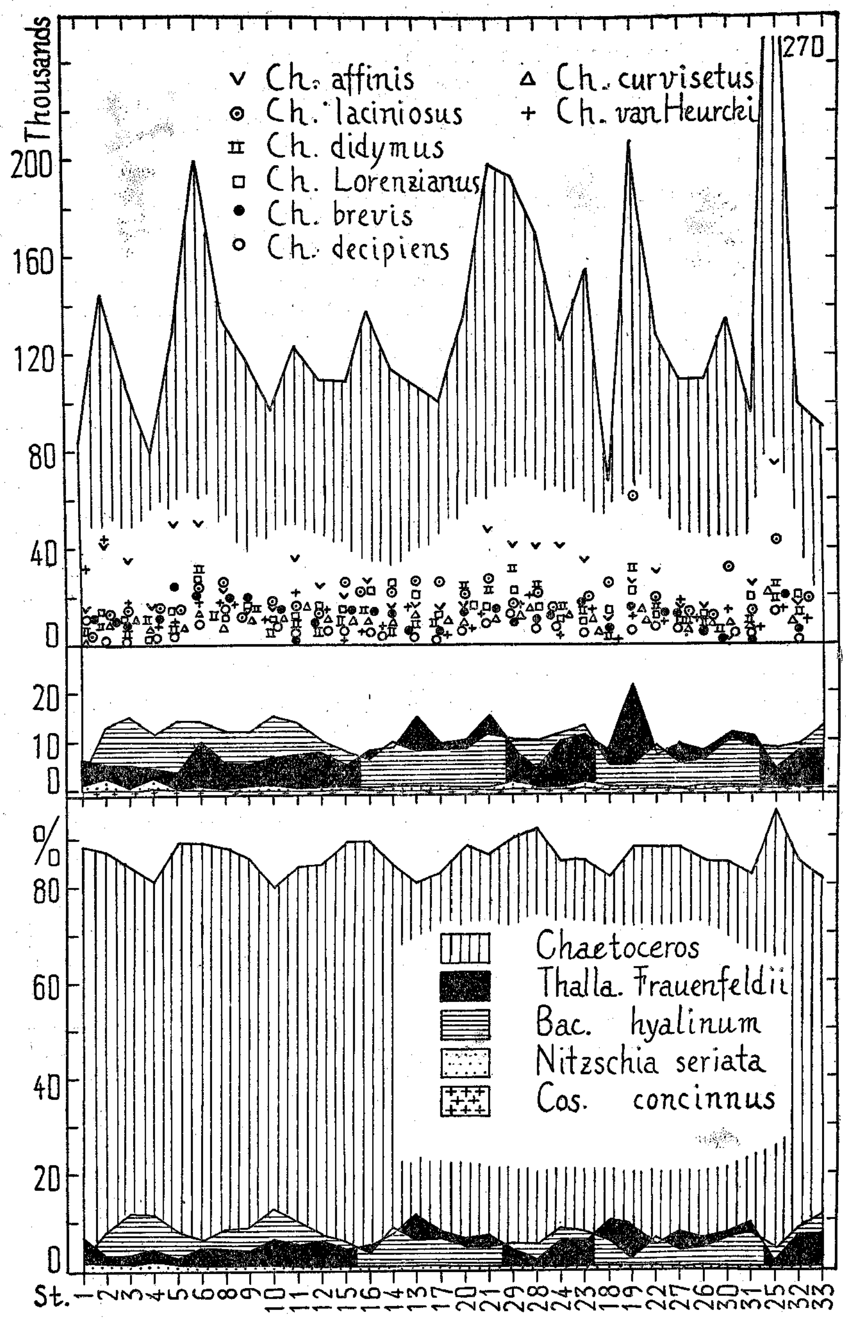

Fig. 7. Cell or colony number of important phytoplankton genera (above) and their percentage composition (below).

Phytoplankton: The leading diatom was *Chaetoceros*, of which 13 different species were recognized. Among the species, *Ch. affinis*, *Ch. laciniosus*, *Ch. Lorenzianus* and *Ch. didymus* were the predominants. The population density of *Chaetoceros* had its maximum in the bay and its minimum in the innermost part of the harbour. *Thalassiothrix Frauenfeldii*, *Bacteriastrum hyalinum*, *Nitzschia seriata* and *Coscinodiscus concinnus* were also important in the frequency of occurrence (Fig. 7). *Skeletonema costatum*, which was frequently recorded in the inner region of Imari Bay, was found neither in this bay nor harhour.

A dinoflagellate, *Ceratium furca* occurred in significant abundance in the central (St. 4) of the harbour and in the innermost part of the bay (St. 16 and 17). The distribution type of this species was similar to that of Imari Bay (YAMAZI, 1952, a). The other plankters found in the material were as follows:

Species	Nagasaki Harbour	Nagasaki Bay
Diatoms		
Ceralaulina bergonii	+	+
Lauderia annulata	+	+
Stephanopyxis palmeriana	+	+
Thalassionema nitzschioides	+	+
Hemiaulus Hauckii	+	+
Asterionella japonica	+	+
Biddulphia sinensis	+	+
Actinoptychus undulatus	+	+
Rhizosolenia alata forma *indica*	+	+
Rh. hebetata forma *semispina*		+
Chaetoceros compressus	+	+
Ch. furca	+	+
Ch. pacificus	+	+
Dinoflagellates		
Ceratium tripos	+	+
Cer. fusus	+	+
Cer. pennatum		+
Cer. macroceros		+
Cer. trichoceros	+	+
Peridinium oceanicum var. *oblongum*	+	+
Per. depressum	+	+

Number of species: Among 48 important plankton species observed in this survey, 20 species were zooplankters, and the remaining 28 were pelagic phytoplankters. The number of species at each station is shown in the following table. It was almost equal at each station.

Table 1. Number of species occurring at each station.

Station No.	Nagasaki Harbour											Nagasaki Bay																					Total species
	1	2	3	4	5	6	8	9	10	11	12	15	16	14	13	17	20	21	29	28	24	23	18	19	22	27	26	30	31	25	32	33	
Zooplankton	15	14	14	17	18	17	16	17	16	17	15	15	16	17	18	18	16	17	17	16	18	17	18	16	19	19	16	17	18	17	19	18	20
Phytoplankton	26	23	20	25	25	23	22	25	27	26	24	23	23	21	22	24	27	26	25	23	21	24	26	27	25	24	21	25	24	24	23	26	32
Total	41	37	34	42	43	40	38	42	43	43	39	38	39	38	40	42	43	43	42	39	39	41	44	43	44	43	37	42	42	41	42	44	52
Mean	40											41																					
Total species throughout the stations	44											48																					

General Consideration on Regional Distribution

Based on the dominant species of the plankton community, Nagasaki Bay and Harbour may be divided into three areas (Fig. 8).

1. *Oithona nana* area.

The harbour and the northern half of the bay were densely occupied by *Oithona nana*. Its densest population was found at 2 stations namely St. 2 in the head of the harbour and St. 15 in the northern part of the bay. The stations of small population in the bay were found along the route of current. The distribution of *Oithona nana* is similar to that observed in Akkeshi Bay, Hakodate Harbour and Imari Bay. This association was represented chiefly by nauplii of *Oithona nana*, and small numbers of copepods, such as *Paracalanus parvus*, *Microsetella norvegica* and *Oithona similis*, were found together. Associated diatoms were *Chaetoceros* spp., *Thalassiothrix Frauenfeldii* and *Bacteriastrum hyalinum*. The animal productivity was very large, but vegetative productivity was relatively small in this area. The hydrological features of this area are as follows; the water is of fairly low salinities, well stratified, yellowish brown in color and small in transparency. It was also characterized by high pH values and high supersaturation degree of oxygen content, excepting a narrow polluted area of the innermost part of the harbour.

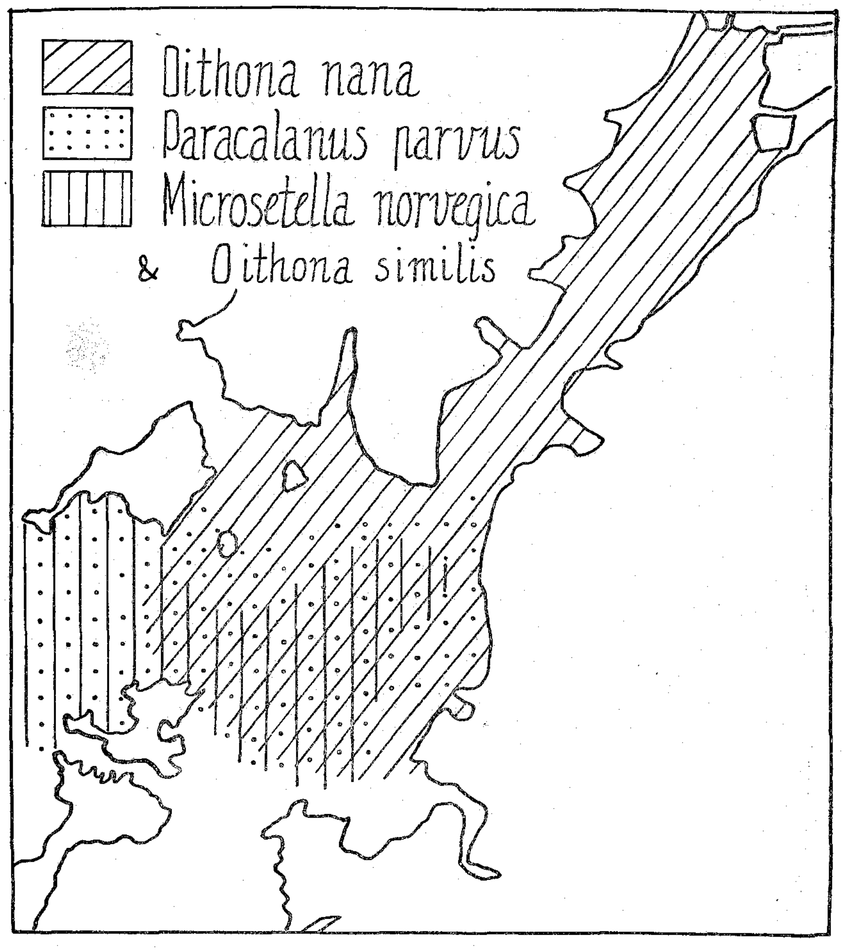

Fig. 8. Distribution of dominant copepods.

2. *Oithona nana—Paracalanus parvus* area.

Oithona nana community was also associated with *Paracalanus parvus, Microsetella norvegica, Corycaeus crassiusculus* and *Oithona similis* in the center of the bay. This area was dominated by a neritic copepod *Microsetella norvegica,* which was very scarsely found in Imari Bay. The number of species in this area was the same as the *Oithona nana* area, but the population density of animals was relatively small. Owing to the abundance of *Chaetoceros,* the density of phytoplankton was larger than that of the above-mentioned area.

The water of this area was relatively stagnant and showed comparatively higher salinity, pH values and supersaturation degree of oxygen content than in the *Oithona nana* area, although it was diffused by polluted water flowing out from the harbour,

3. *Paracalanus parvus—Microsetella norvegica* area.

The neritic copepods, such as *Paracalanus parvus, Microsetella norvegica* and *Oithona similis* were found near the mouth of the bay, whence open sea water invades into the bay and harbour, and formed an intermingling area with the *Oithona nana* area in the central part of the bay. The water of this area was relatively stagnant and showed higher transparency and lower water color than in other areas.

Summary

In conclusion, the productively of diatoms in the Nagasaki Bay and Harbour was greater than that of the Imari Bay. This is probably due to the continued supply of abundant nutrient matter from the city of Nagasaki at the head of the harbour. The widespread distribution of *Oithona nana* extends to the mouth of Nagasaki Bay where the oceanic influx is rather strong.

The larger population of the strictly inshore copepod, *Oithona nana* and poorer population of smaller offshore copepods in the plankton composition is correlated with an advanced degree of bay characters as contrasted with the oceanic characters. This fact may be taken as a proof that the Nagasaki Bay is of stronger embayment characters than the Imari Bay.