広島湾太田川河口域における近底層プランクトンの分布,特に塩分との関係

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Distribution of Near-bottom Plankton in the Ohta River Estuary, Hiroshima Bay, in Relation to Salinity[1),2)]

HIROMICHI IMABAYASHI[3)] AND TAKUO ENDO[3)]
Faculty of Applied Biological Science, Hiroshima University, Fukuyama 720

Abstract

The distribution of near-bottom plankton was investigated by towing a sledge along the bottom in spring and early summer 1982 in the Ohta River estuary, Hiroshima Bay. Throughout the entire estuary, decapod larvae, copepods (*Calanus sinicus* and *Centropages abdominalis*) and a chaetognath (*Sagitta crassa* f. *naikaiensis*) were predominant and intruded into the upward river sites to a lesser extent. However, *S. crassa* f. *naikaiensis* was considerably numerous upward of river mouth in early summer when the flow rate was one-third lower than in spring. More benthic animals which are usually dwelling immediately above the bottom, e.g., mysids, macruran decapods and gammaridean amphipods, occurred in small and constant numbers. For mysids, *Hypererythrops spinifera* and *Mysidopsis japonica* were always distributed in the sea region, whereas *Neomysis awatschensis* was confined to the river region. Only a small number of a freshwater copepod *Cyclops vicinus* was collected downward of the branch with largest stream flow in Ohta River. Each species of near-bottom plankton had a differential range of tolerance for salinity.

Many species of plankton inhabit on and immediately above the bottom (BIERI & TOKIOKA 1968, OMORI 1969, MURANO 1970a, 1970b, GRICE & HÜLSEMANN 1970, VALBONESI & MURANO 1980), and are generally referred to as near-bottom plankton (MURANO 1979). Since these plankton organisms are difficult to capture with commonly used plankton nets, their species composition, abundance and distribution have not yet been sufficiently clarified, especially in estuaries of Japan where large fluctuations in environmental conditions occur in space and time (HOPKINS 1965, CONNELL 1974, KADOTA & TANAKA 1984).

The Ohta River estuary, Hiroshima Bay, investigated in this study, is ranked second in flow rate among rivers of the Inland Sea with an annual average of $72.0\,m^3 \cdot s^{-1}$, and also exhibits a large tidal oscillation with a spring range of 290 cm (TOKYO ASTRONOMICAL OBSERVATORY 1985). According to OHTA RIVER WORK OFFICE (unpubl.), ninety-five percent of the total freshwater of Ohta River runs off into the sea through its five branches, of which 70 %, 15 % and 10 % flows out through Hon-, Motoyasu- and Kyobashi-Branches, Tenma-Branch, and the drainage canal, respectively. Seawater intrudes into upstream area, forming a salt wedge along the bottom layer in synchronization with tidal oscillation.

This study attempts to clarify the relationship between the distribution of near-bottom plankton and environmental variables, especially salinity, in the Ohta River estuary.

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[2)] 広島湾太田川河口域における近底層プランクトンの分布，特に塩分との関係
[3)] 今林博道・遠藤拓郎，広島大学生物生産学部

Materials and Methods

The Ohta River estuary can be topographically divided into two: sea and river regions. This study was carried out in both sea region (Stns. OS1, OS2, OS3, OS4, OS6) and river region (Stns. OR1, OR2, OR3, OR4, OR6, OR7, OR9, OR10, OR12, OR13, OT12) which are covered with sediments of soft mud and sandy mud to sand, respectively (Fig. 1).

The survey was conducted in the daytime from 23 to 26 April and from 10 to 13 June 1982. The river region was investigated during the time of high water by a small motorboat, and the sea region by the T/RV "Toyoshio-maru" (320 tons), Hiroshima University. The depth of sampling stations varied from 10.1 to 16.3 m in the sea region and from 1.0 (Stn. OT12) to 9.0 m (Stn. OR13) in the river region. Stn. OT12 is located about 1 km upward from the Gion and Ohshiba sluices which control the flow rate of freshwater downstream.

The near-bottom plankton was collected by towing a sledge (Fig. 2) along the bottom. The sledge has two equal sized nets with a mouth opening of 11×39 cm and 500 μm mesh aperture. These are separated 20 cm apart from each other. Therefore, the lower sledge net is favorable for the collection of organisms dwelling within 25 cm of the bottom layer. The sledge was towed at a ground speed of approximately 1 knot for 5 min in order to avoid clogging the nets with sediment particles stirred up during towing. This speed resulted in a filtering volume of 13 m^3, since near-bottom current velocity was estimated to be very small as noted

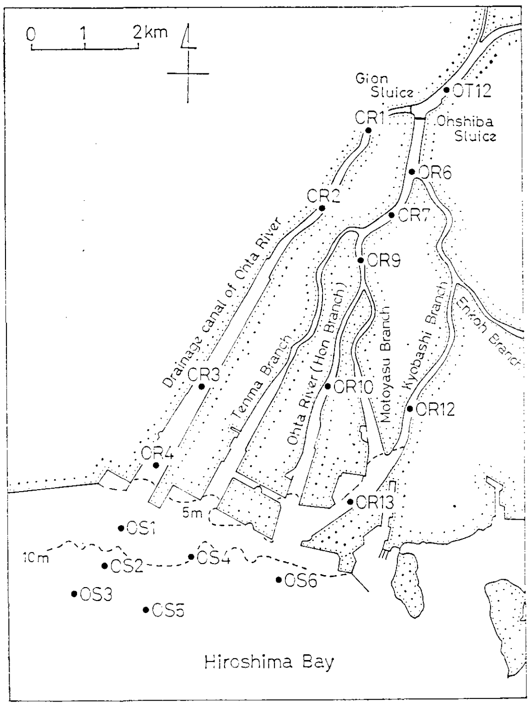

Fig. 1. Sampling stations in Ohta River and its estuary. Samplings were made at 16 stations (solid circles) on 23-26 April and 10-13 June 1982.

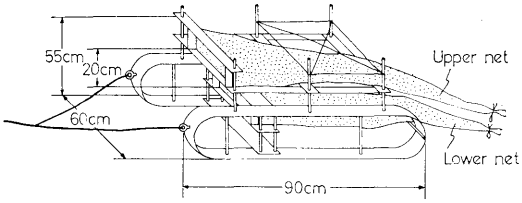

Fig. 2. Sledge with two nets used to collect near-bottom plankton.

later. The samples collected were immediately preserved in 5 % buffered formalin, and the whole sample or split subsamples were used for identification and counting. Identification to species is difficult for gammaridean amphipods at present because the taxonomy of this group has not yet been well established. The density of near-bottom plankton was expressed as number of individuals per unit volume (m^3) of water filtered by both upper and lower nets.

Salinity, temperature and dissolved oxygen concentration of water were simultaneously measured during towing by means of a water quality analyzer ("Mark VI", Martek Co. Ltd.) at 1 to 2 m depth intervals of the water column, including just above the bottom. The near-bottom stream flow was nearly slack around high water period, as observed at a site 1 km downstream from Stn. OR2, with an average velocity of 10 $cm \cdot s^{-1}$ (SUNAGA & ENDO 1985). Hence, the water volume filtered by the sledge may be considered to be proportional to the towing distance. During the past 10 days before the survey, the flow rate of Ohta River averaged 99.4 $m^3 \cdot s^{-1}$ in spring and 32.8 $m^3 \cdot s^{-1}$ in early summer (OHTA RIVER WORK OFFICE unpubl.).

Results

Environmental Conditions

At all sampling stations, the salinity and temperature of near-bottom water ranged from 15.5 to 33.5 ‰ and 12.6 to 18.5°C, respectively, in spring, and from 23.6 to 33.7 ‰ and 16.0 to 21.5°C, respectively, in early summer. The difference in salinity between both sampling occasions was small at each station with an average of 4.5 ‰. As shown in Fig. 3, seawater intruded extensively into the river region along the bottom, forming a salt wedge as far as to the Gion and Ohshiba flood gates. The near-bottom salinity at Stns. OR6 and OR7 was not measured in spring, but was estimated to be nearly 10 ‰ and 20 ‰, respectively, based on the vertical and horizontal salinity gradients (Fig. 3) and the tidal level of June 1983. The salinity at Stn. OT12 was probably zero because the intrusion of brackish water was cut off by the Gion and Ohshiba flood gates, although no measurement was made. The saturation of dissolved oxygen varied little between spring (60–100 %) and early summer (64–100 %) throughout the entire estuary. The lowest value was always observed at Stn. OR1 in both seasons.

Distribution of Near-bottom Plankton in Spring

Major taxonomic groups of near-bottom plankton in both sea and river regions were copepods

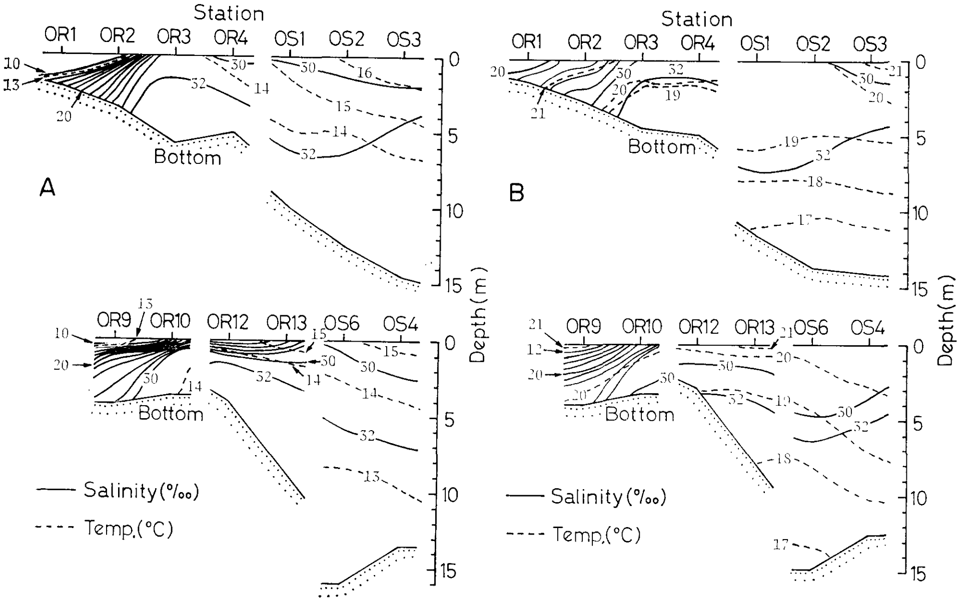

Fig. 3. Vertical profiles of salinity and temperature in the Ohta River estuary. A: April 1982, B: June 1982.

and decapod larvae (zoeal and postlarval stages), occupying 64.4% and 28.1%, respectively, in terms of individual number. These animals were collected by both upper and lower nets (Table 1). A small number of mysids, gammaridean amphipods and macruran decapods (5.1%) were obtained only by the lower net. Thus, most of the dominant animals are of a pelagic life form adaptable to the entire water column.

The total density of near-bottom plankton was high in the sea region varying from 161 indiv·m^{-3} at Stn. OS6 to 1,279 indiv·m^{-3} at Stn. OS1 (Fig. 4). There was a drastic decline in individual number from the sea region to the river region, especially in the drainage canal with a minimal flow rate. Such distributional pattern primarily reflects the abundances of dominant animals such as copepods and decapod larvae, and is not influenced by those of mysids, gammaridean amphipods and decapods dwelling close to the bottom. In the river region the total density of organisms decreased gradually to a minimum level of 0.4 indiv·m^{-3} at Stn. OT12, the uppermost station in the present survey. At Stn. OR13 situated near the river mouth, the highest density among the river stations was observed owing to the appearance of two marine species of mysids.

Larger marine calanoid copepods, *Calanus sinicus* and *Centropages abdominalis*, were distributed numerously in the sea region, while their densities were low in the river region, especially at two upstream stations (OR1, OR7). A similar tendency was also found in the distribution of a smaller neritic calanoid, *Acartia clausi*, which was collected in low numbers by this sampling apparatus due to its slightly smaller body size relative to the mesh size of the netting employed. Some specimens of a freshwater cyclopoid, *Cyclops vicinus*, were

TABLE 1. TOTAL NUMBER OF INDIVIDUALS OF THE NEAR-BOTTOM PLANKTON COLLECTED AT SAMPLING STATIONS IN THE OHTA RIVER ESTUARY IN APRIL AND JUNE 1982.

Organisms	April		June	
	Lower net	Upper net	Lower net	Upper net
Sagittoidea				
Sagitta crassa f. *naikaiensis*	236	756	886	1,107
Copepoda				
Calanus sinicus	6,051	14,013	21	7
Centropages abdominalis	646	4,494	12	22
Acartia clausi	37	91	—	1
Corycaeus affinis	—	33	—	—
Paracalanus parvus	2	—	—	—
Eurytemora pacifica	28	3	—	—
Cyclops vicinus	20	22	—	—
Cyclopoid species	—	—	2	1
Harpacticoid species	444	21	—	—
Unidentified species	—	2	—	2
Mysidacea				
Hypererythrops spinifera	906	—	155	—
Mysidopsis japonica	277	—	68	—
Parastilomysis paradoxa	—	—	2	—
Neomysis awatschensis	105	2	119	—
Mysidopsis sp.	3	—	—	—
Gammaridea	719	6	299	2
Macrura				
Crangon affinis	102	—	145	—
Other species	18	—	31	—
Decapod larvae	1,893	9,848	9,307	31,312
Total	11,487	29,291	11,047	32,454

collected only at the upward reaches of the Hon-Branch (Stns. OR6, OR7, OR9). At almost identically low levels of abundance, harpacticoid copepods and a calanoid copepod, *Eurytemora pacifica*, occurred in the downward river region. A chaetognath, *Sagitta crassa* f. *naikaiensis*, occurring widely in coastal waters, was numerous in the sea region, but extremely few in the river region, as in the case of decapod larvae.

Of three dominant species of mysids, *Hypererythrops spinifera* and *Mysidopsis japonica* had a similar distribution pattern, being restricted in the sea region with partial intrusion into the river mouth (Stn. OR13). However, *Neomysis awatschensis*, a brackish-water mysid, occurred only in the river region. A small decapod, *Crangon affinis*, was nearly identical in its distributional pattern to the former two species of mysids.

Distribution of Near-bottom Plankton in Early Summer

In early summer when the water temperature increased by about 8°C higher than in spring, the total density of near-bottom plankton ranged widely from 0.6 to 1,578 indiv$\cdot$m^{-3} (Fig. 5), of which 93.4% was composed by decapod larvae (Table 1). The distributional pattern of

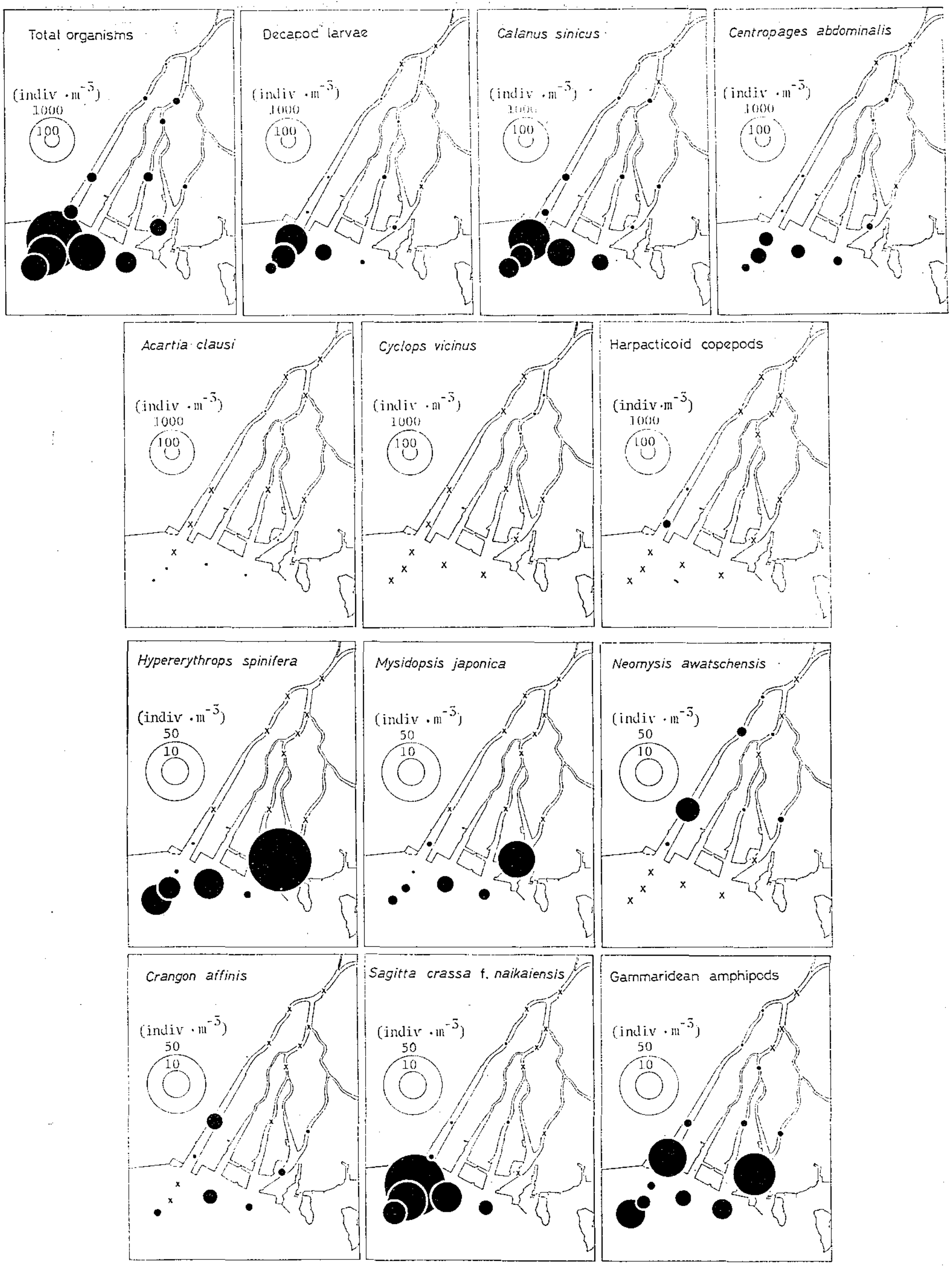

Fig. 4. Distribution of the near-bottom plankton in the Ohta River estuary (April 1982). Size of circles is proportional to the abundance (individuals·m^{-3}). Negative stations are indicated with ×.

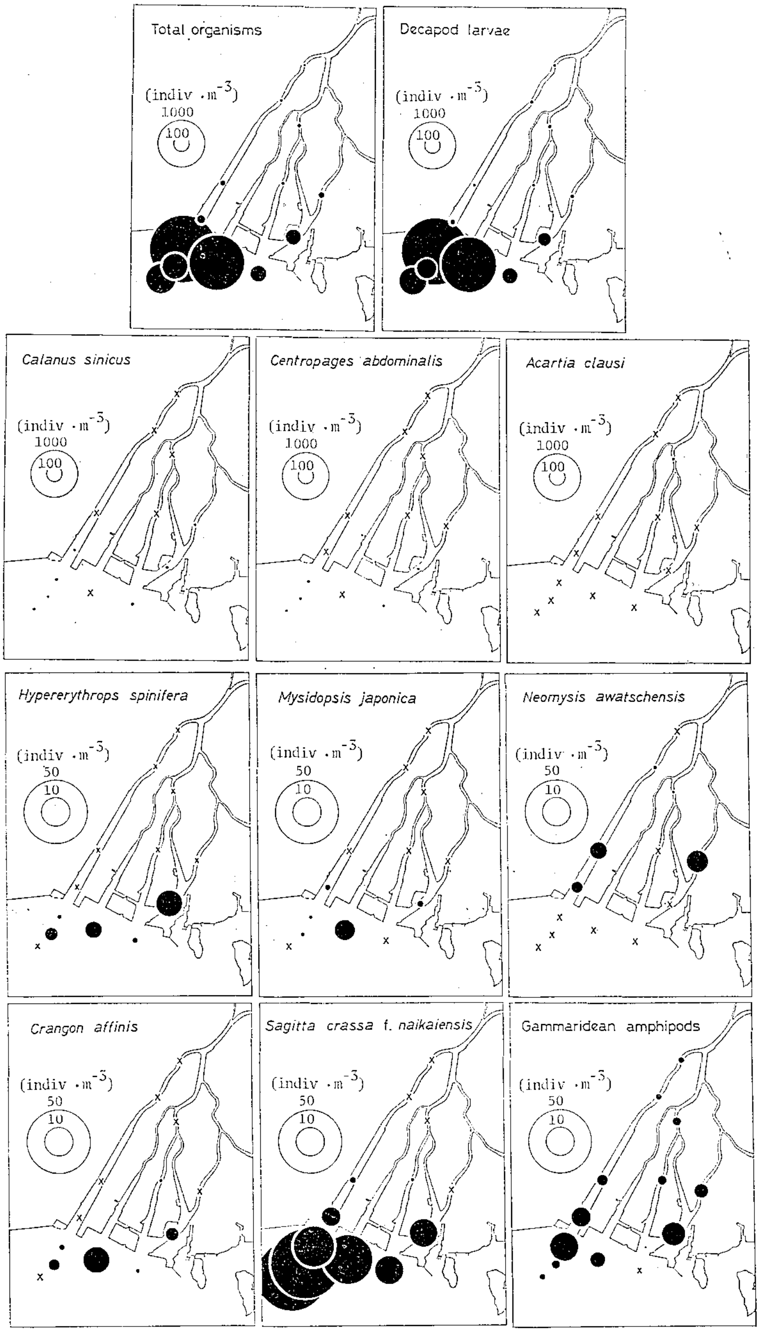

Fig. 5. Distribution of the near-bottom plankton in the Ohta River estuary (June 1982).

each species was almost similar to that of the spring time (Fig. 5). The majority of *S. crassa* f. *naikaiensis* was obtained in the sea region, and its intrusion into the river region (Stns. OR4, OR13) was more striking than in spring when the flow rate was three times larger than in early summer. Since copepods decreased markedly in both individual number and species number as compared with the spring samples, the distributional pattern of each copepod species was not clarified, except for 3 species shown in Fig. 5.

The density of mysids also showed a slight decline, but the distributions of the three dominant species differed little from those of the spring time (Fig. 5); *H. spinifera* and *M. japonica* were collected in the sea region and *N. awatschensis* in the river region. *C. affinis* disappeared from a few stations (OR3, OR4, OR12) of the river region, where it occurred in spring. Gammaridean amphipods consisting of several unidentified species were distributed at various estuarine stations except upstream stations (OR6, OR7, OT12).

Effect of Environmental Conditions on the Abundance of Major Plankton

Changes in the abundances of dominant animals were plotted against temperature and salinity of the near-bottom water (Fig. 6). Decapod larvae and four species of copepods (*C. sinicus, C. abdominalis, A. clausi* and *C. vicinus*) occurred over the temperature range of 12.6–18.5°C in spring, but these copepods disappeared markedly in early summer (16–21.5°C). Decapod larvae, *C. sinicus, C. abdominalis* and *A. clausi* occurred over an extended salinity range from 15 to 33.7‰. *C. vicinus*, however, was collected only in low numbers over a range from 0 to

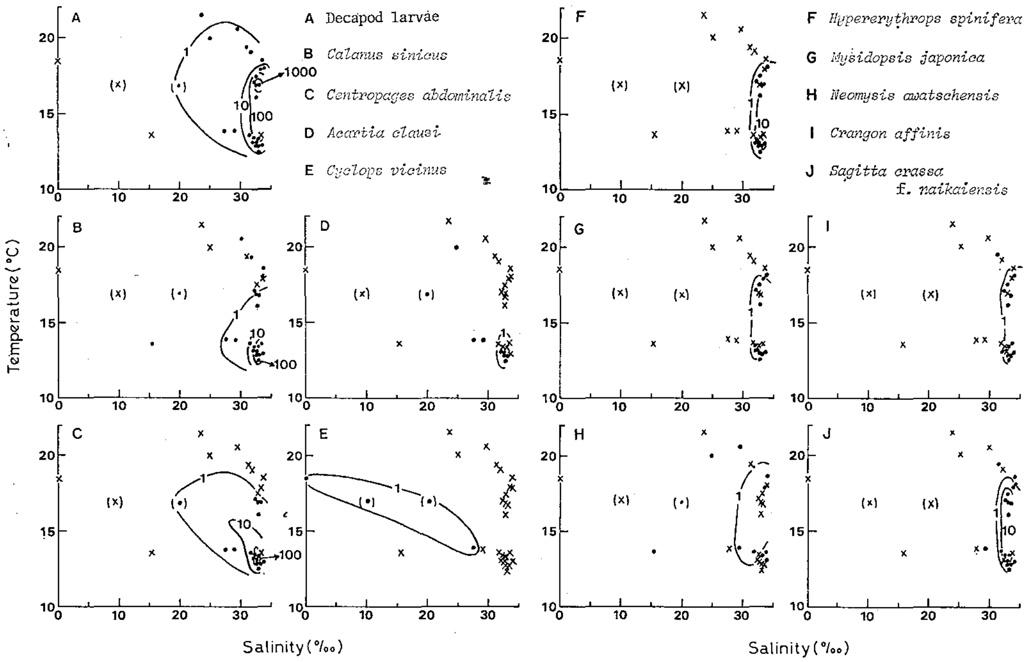

Fig. 6. Abundance of major species of near-bottom plankton in the Ohta River estuary in relation to salinity and temperature (April and June 1982). Isopleth denotes the abundance (individuals·m^{-3}) for each animal. Estimated data for salinity are in parentheses.

27.5‰. The mysids appeared over a wide range of water temperature (12.6-21.5°C). *H. spinifera* and *M. japonica* occurred only at salinities above 32‰, but *N. awatschensis* was more euryhaline, inhabiting over a salinity range from 15.5 to 33.5‰. The distribution of *C. affinis* was restricted at salinities greater than 31‰. A similar distributional pattern was also observed for *S. crassa* f. *naikaiensis.*

Discussion

There was little change in the total abundance of near-bottom plankton between spring (April) and early summer (June). In both seasons, they occur in great numbers as compared with other seasons (September and November) (IMABAYASHI & ENDO unpubl.). However, great changes were seen in their composition. In early summer, *S. crassa* f. *naikaiensis* and decapod larvae increased and copepods decreased in number as compared with spring (Table 1). Concerning the distributional pattern of benthic species, *H. spinifera*, *M. japonica*, *N. awatschensis* and *C. affinis* showed little seasonal change. Similarly, no seasonal difference of ambient salinity was observed among sampling stations, although there was an increase in water temperatures of 3.0-4.6°C in the sea region and 4.8-7.9°C in the river region from spring to early summer. The distributions of typically pelagic marine animals such as decapod larvae and *S. crassa* f. *naikaiensis* were extended upstream, and a freshwater copepod *C. vicinus* was restricted to upstream stations in early summer when the flow rate had dropped by one-third that of spring. Accordingly, salinity is likely to be one of the critical environmental variables in limiting the distribution of near-bottom plankton in the Ohta River estuary. As summarized in Fig. 7, each of the four copepod species, together with decapod larvae, displayed differential tolerance to various ranges of salinity. Of marine copepods collected in the study, the largest calanoid, *C. sinicus*, showed the greatest tolerance to decreased salinity as low as 15‰, while *A. clausi* and *C. abdominalis* were less tolerant (20‰).

These values well agree with those obtained in the Nagara River estuary, central Japan,

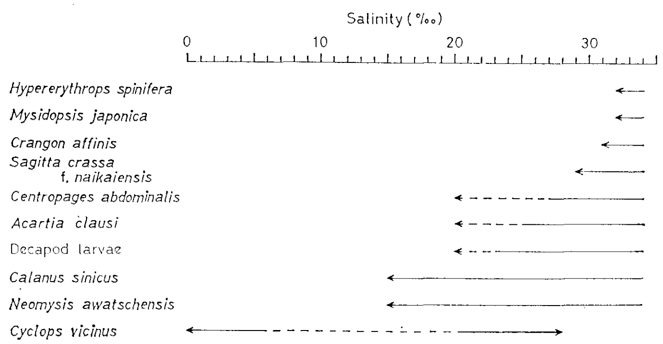

Fig. 7. Salinity ranges for the occurrence of major species of near-bottom plankton in the Ohta River estuary (April and June 1982). Dotted lines are drawn, based on the estimated salinity values.

with a tidal range of 190 cm (YAMAZI et al. 1967). ONBÉ (unpubl.), who investigated the vertical distribution of zooplankton at the same time with our study throughout the whole water column, excluding the near-bottom layer, pointed out that the lowest values of salinity at which *C. sinicus* and *C. abdominalis* were collected were 12‰ and 21‰, respectively. These values are nearly identical with those of our study. ONBÉ (unpubl.) also showed that *A. clausi* occurred in low numbers at waters of salinity as low as 5‰, although the abundance decreased rapidly at waters less than 20‰, which corresponds to the lowest salinity at which it appeared in near-bottom waters. The apparent discrepancy found in salinity tolerance for *A. clausi* may be attributed to a poor collecting efficiency of the sledge for this smaller species of low abundance. UEDA (1986) recently concluded that Japanese "*A. clausi*" consists of two species, *A. omorii* and *A. hudsonica*, and no other related species occur in Japanese waters. We have used the older terminology, *A. clausi*, because no precise re-examination of species had been made.

The occurrence of the freshwater copepod, *C. vicinus*, extended over a wide salinity range as compared with the case examined by MIZUNO (1979), who estimated its tolerable salinity to be from 1 to 5‰ in many brackish-water lakes of Japan. Its occurrence at high saline waters (27.5‰) of the Hon-Branch may be due to dead individuals from the upstream freshwater region, since this species was not collected at Stn. OR1 which had a lower salinity (15.5‰).

The habitats of two mysids, *H. spinifera* and *M. japonica*, and a decapod, *C. affinis*, were almost always limited to the sea region and to Stn. OR13 which had a salinity greater than 32‰, although *C. affinis*, unlike the mysids, shifted its distribution offshore to a considerable extent in early summer. This tendency in *C. affinis* coincides with the results obtained in the estuary of Sendai Bay, northern Japan (KOSAKA 1970). *N. awatschensis* was taken only from several river stations which had a wide salinity range of 15 to 32‰, excluding Stn. OR13 where seawater (32–33‰) was always present at the bottom layer. II (1964) reported that many individuals of this species were collected in low saline waters of the Yoshino River estuary, Shikoku, and Kojima Bay, Okayama, and a small saline pond (7–8‰) located near Dairen, northeastern China. This species can be regarded as a typical brackish-water form.

The near-bottom plankton collected by the sledge in the Ohta River estuary can be divided broadly into two life forms: benthic and pelagic animals. The former exhibits relatively definite distributions connected with the stability of the salt wedge, while the latter is easily transported horizontally to upstream area with seawater intrusion as indicated by JACOBS (1968).

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