J. Fac. Appl. Biol. Sci.,
Hiroshima Univ. (1992), **31** : 99～119

Seasonal Geographical Distribution of Zooplankton in Hiroshima Bay and Its Adjacent Waters, the Inland Sea of Japan

Shin-ichi UYE, Yoichi AYAKI and Takashi ONBÉ

Faculty of Applied Biological Science, Hiroshima University,
Higashi-Hiroshima 724, Japan

Received October 16, 1992

Abstract The geographical distribution of zooplankton was investigated in Hiroshima Bay, Aki Nada and Akitsu Bay in April, June, September and December, 1989. The density of total zooplankton was highest throughout the year in the northern Hiroshima Bay, followed in order by the southern Hiroshima Bay, Aki Nada and Akitsu Bay. A significantly positive relationship was found between the abundance of total zooplankton and chlorophyll concentration. Copepods were the major constituents, accounting for 50-98% (overall mean: 83%) of the total zooplankton. Among copepods, *Oithona* was most abundant, in particular in the northern Hiroshima Bay. *Paracalanus* was distributed rather homogeneously over the study area, and *Oncaea* and *Microsetella norvegica* occurred mainly in the southern Hiroshima Bay. The regional distribution pattern of the dominant copepod species was almost the same as the pattern observed 30-40 years ago, although the occurrence of oceanic zooplankters was not so common as before.

Key words: eutrophication, geographical distribution, Hiroshima Bay, zooplankton

INTRODUCTION

There are at least 3 papers (YAMAZI, 1952; KADO, 1954; HIROTA, 1968) which report the species composition and the seasonal/regional distributions of zooplankton in Hiroshima Bay. YAMAZI (1952) performed a plankton investigation for the first time in this bay in October, 1951, and reported the taxonomic composition and the regional distribution of some important phyto- and zooplankton. However, the area of his survey was confined to the innermost part of Hiroshima Bay. KADO (1954) reported the seasonal occurrence of copepods and chaetognaths in Hiroshima Bay and Hiro Bay by examining the samples collected monthly from November, 1951, to December, 1952. HIROTA (1968) surveyed the species composition and the regional distribution of zooplankton at two stations in Hiroshima Bay in June, 1963.

These surveys were conducted some 30-40 years ago, when the industrialization and urbanization along the coast of Hiroshima Bay did not arise or were at least in a primitive stage except for Hiroshima City. Much have been changed in the geographical features along the coast in 1960s and 1970s, a period of high economic growth. Many beaches and shoals were reclaimed for the construction of factories and houses, and the rapid urbanization and industrialization resulted into the eutrophication of Hiroshima Bay. Due to eutrophication of the area, the outbreak of red-tides became common (HADA, 1974). Accordingly some changes might have happened in zooplankton community. Hence, it is worth recording the present day's status in zooplankton composition and regional/seasonal distributions to compare to the past results.

From the trophodynamic point of view, zooplankton is the major food for planktivorous fish. The most important planktivorous fish in Hiroshima Bay and Aki Nada is anchovy (*Engraulis japonica*). Total catch of anchovy including various growth stages was 14,572 tons in Hiroshima Prefecture in 1989 (HIROSHIMA PREFECTURAL STATISTICS OFFICE, 1990). In particular, dried anchovy larvae (locally called as "chirimen" and "iriko") produced in this area are famous for their high quality. We investigated previously the vertical and horizontal distributions of copepod nauplii, which are important food for newly hatched larvae, in Hiroshima Bay (UYE and YAMAOKA, 1990). This time, we investigated net zooplankton (body size is larger than ca. 100 μm), which is an important food item for anchovy older than ca. 1 week after hatch.

MATERIALS AND METHODS

Zooplankton investigations were made during 24–27 April, 4–7 July, 18–21 September and 4–8 December, 1989, in Hiroshima Bay, Aki Nada and Akitsu Bay. Zooplankton was collected by a vertical haul of a Norpac net (mouth diameter: 0.45 m, length: 2 m, mesh opening: 96 μm) from the T&R/ V *Toyoshio Maru* at 19 stations (Fig. 1). Immediately after sampling, zooplankton was washed into 500 ml plastic bottles and preserved in ca. 10% formalin-seawater solution. Later, the samples were split into subsamples (1/8–1/32 original

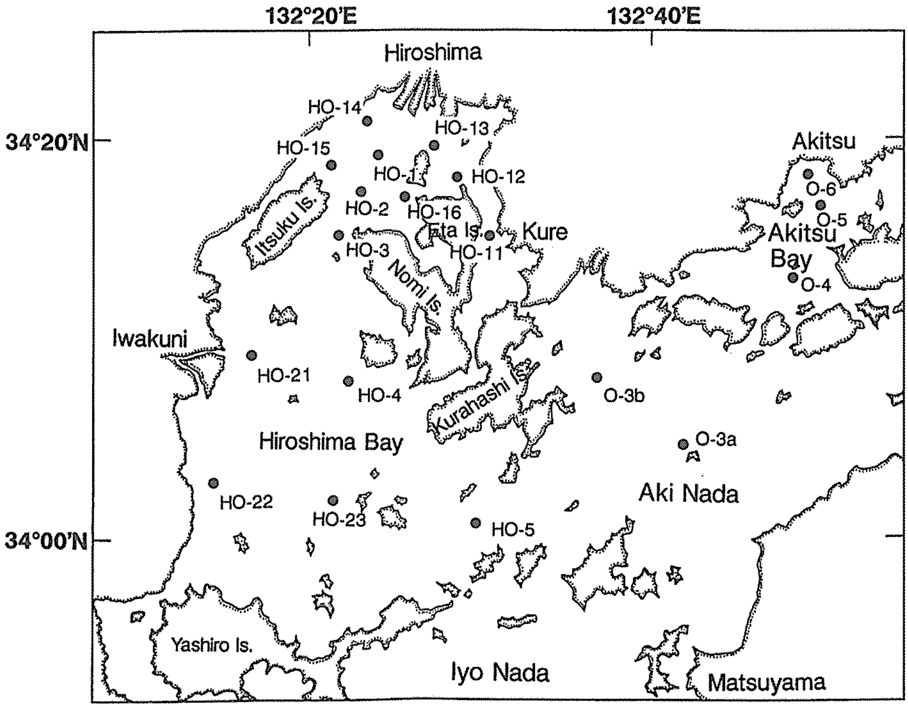

Fig. 1 Map showing the location of sampling stations of zooplankton.

sample), and identified and counted under a stereo-microscope. Since we counted all organisms including larval stages, e.g. nauplii and copepodites of copepods, taxonomic levels for the identification varied from species to phylum. Number of individuals counted was converted to the density per unit volume of water (indiv. m^{-3}) according to the reading of a flowmeter mounted in the net.

Before zooplankton sampling, vertical profiles of temperature and salinity were determined by a STD (Alec Co.). Water of discrete depths (5–10 m intervals from the surface) was filtered with Millipore (type HA, pore size: 0.45 μm) filters, which were then extracted in aqueous acetone to determine chlorophyll concentration spectrophotometrically (STRICKLAND and PARSONS, 1977). These values were integrated for the water column and divided by the depth to determine the average values at respective stations.

RESULTS

Environmental Variables

Environmental parameters, i.e. average temperature, salinity and chlorophyll concentration, at each station are shown in Table 1. Temperature followed a general seasonal fluctuation: it varied between 18.7 and 21.7°C in April, 23.2 and 24.2°C in July, 24.1 and 25.7°C in September, and 16.5 and 17.8°C in December. Salinity showed a consistent geographical variation in each observation: it was lowest at stations (e.g. Stns. HO-1, 13, 14) in the northern Hiroshima Bay (north of Miyajima Seto between Itsuku Island and Nomi

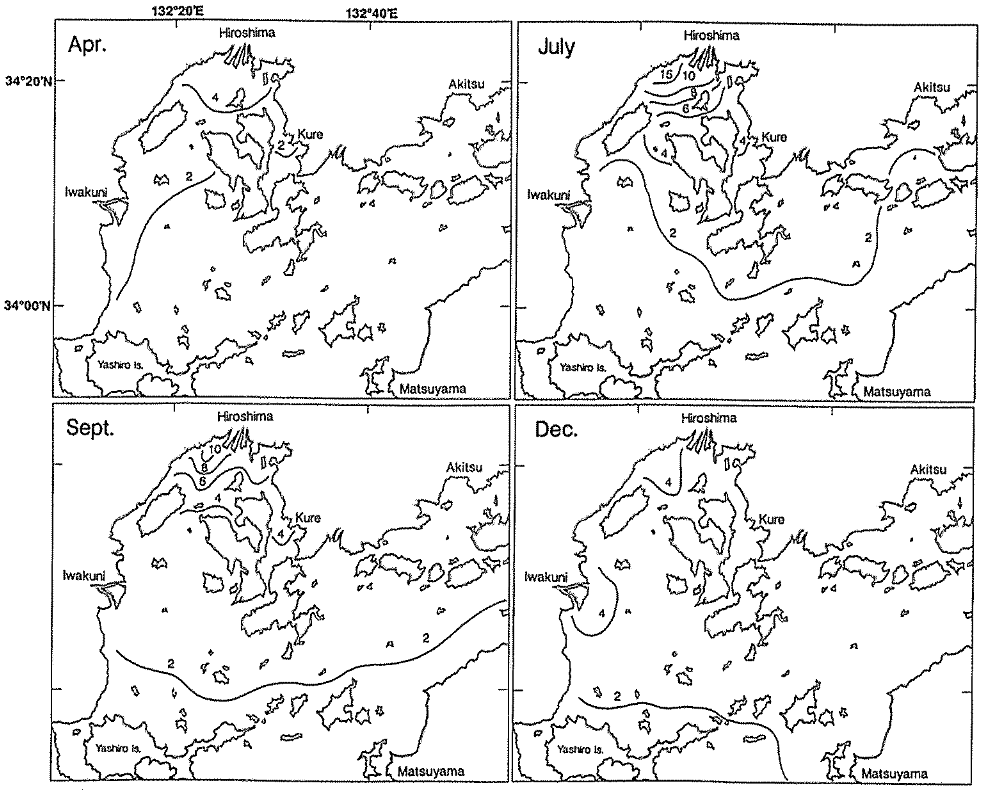

Fig. 2 Geographical distribution of chlorophyll concentration.

Table 1 Average temperature (°C), salinity (‰) and chlorophyll *a* ($\mu g\ l^{-1}$) at respective sampling station.

Station	HO-11	12	13	14	15	16	1	2	3	4	21	22	23	5	O-3a	3b	O-4	O-5	O-6
April 25-27, 1989																			
Temp.		19.5	19.3	19.5	21.1	18.7	19.3	18.8	19.2	19.3	19.6	20.3	19.7	19.1	19.3	19.5	20.3	20.2	21.7
Sal.		32.3	32.2	32.0	31.0	32.6	31.7	32.6	32.8	33.2	32.9	32.4	33.4	33.1	33.3	33.3	33.6	33.2	33.1
Chl. *a*		9.5	10.8	12.6	19.9	4.0	7.0	2.6	2.5	3.2	1.9	1.9	1.8	1.5	2.3	2.4	1.8	2.4	4.0
July 4-7, 1989																			
Temp.	23.7	23.5	23.5	24.0	24.0	24.0	24.1	24.1	23.2	23.2	23.2	24.0	24.2	24.2	24.2	24.2	24.2	24.2	24.2
Sal.	32.8	32.8	32.8	32.3	32.4	32.8	32.4	32.7	33.3	33.4	33.4	33.1	32.9	33.4	33.7	33.7	33.5	33.5	33.4
Chl. *a*	3.4	3.4	6.8	4.4	5.5	4.0	3.4	5.2	2.4	1.8	1.5	2.3	2.8	1.8	1.2	1.3	1.2	1.4	1.8
September 18-21, 1989																			
Temp.	24.9	25.1	25.2	25.6	25.0	24.8	25.3	24.7	24.1	24.6	25.2	24.5	24.7	24.5	24.9	25.1	25.3	25.6	25.7
Sal.	31.3	30.6	30.4	29.0	30.9	31.5	28.6	30.9	30.7	32.1	31.8	29.2	31.9	32.3	32.1	32.0	31.8	31.6	31.3
Chl. *a*	4.5	9.7	5.7	15.6	8.3	3.9	7.0	4.2	3.6	3.7	2.8	2.1	3.0	2.6	1.9	2.7	2.2	2.3	4.0
December 4-8, 1989																			
Temp.	17.0	17.2	17.2	16.8	17.3	17.2	16.5	16.7	17.3	17.6	17.7	17.5	16.9	17.6	17.8	17.7	17.6	17.3	16.5
Sal.	31.7	31.9	31.6	31.2	31.5	32.0	31.2	31.6	32.5	33.0	32.5	32.4	32.1	32.5	32.7	32.7	32.5	32.4	32.3
Chl. *a*	2.1	2.5	3.4	4.5	4.7	3.1	4.0	5.2	3.2	3.9	2.9	5.6	2.3	3.2	2.3	2.9	2.0	1.9	2.1

Island) due to discharge mainly from Ohta River. Seasonally, it was lowest in September. Chlorophyll concentration also showed a consistent geographical distribution: it was highest in the northern Hiroshima Bay and decreased offshore (Fig. 2). The highest chlorophyll concentration (19.9 μg l^{-1}) was observed at Stn. 15 in July.

Zooplankton Distribution

1. Total zooplankton (Fig. 3)

In April, total zooplankton abundance was high (24-29x10^3 indiv. m^{-3}) at Stns. HO-1, 11, 13, 14 and 15, but was low at Stns. HO-23, O-6 (2-3x10^3 indiv. m^{-3}). Copepods are the major components of the zooplankton, comprising 45.6 to 93.4% (mean: 72.8%) of the total abundance (Table 2). Among copepods, *Oithona* and nauplii were most numerous. A cladoceran *Evadne nordmanni* occurred abundantly in the northern Hiroshima Bay.

In July, total abundance was higher in the northern Hiroshima Bay than the other areas, being particularly high (174x10^3 indiv. m^{-3}) at Stn. 14. Zooplankton occurred scarcely at Stns. HO-5 and O-6, where the density ranged from 3x10^3 to 13x10^3 indiv. m^{-3}. The major components of the zooplankton were again copepods (mean: 86.1%), among which *Oithona*, *Paracalanus* and nauplii were abundant (Table 3). In zooplankton other than copepods, a larvacean *Oikopleura dioica* was abundant.

Between-station mean of total zooplankton abundance was highest in September. Zooplankton was abundantly distributed in the northern part and western part of Hiroshima

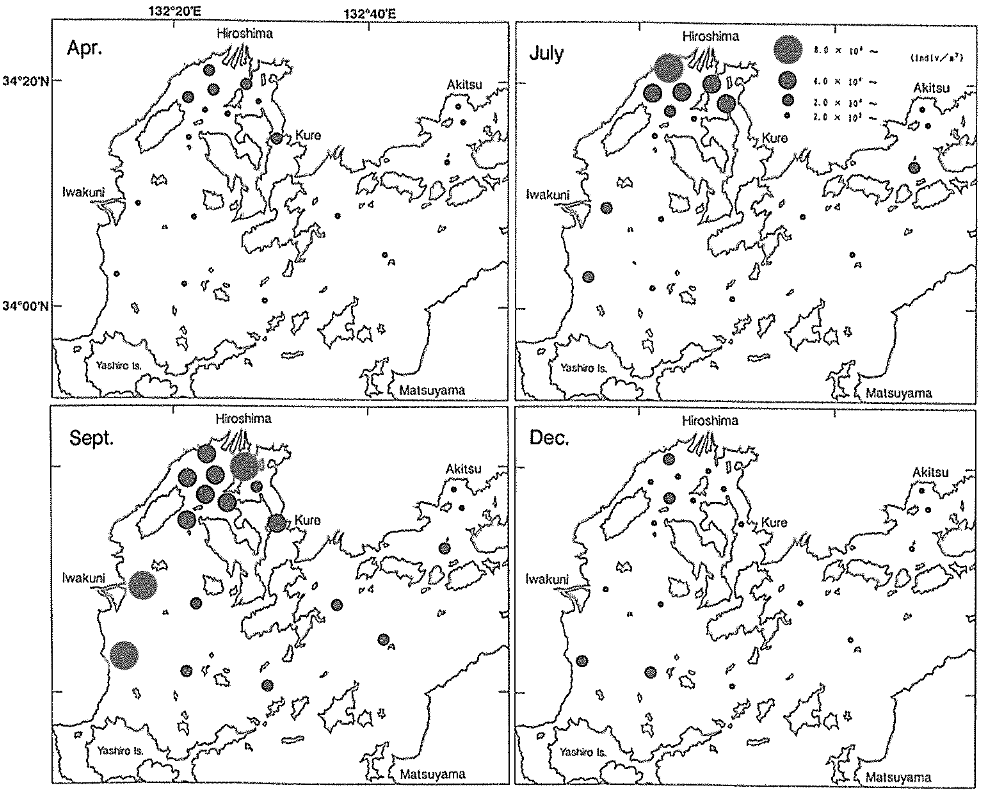

Fig. 3 Geographical distribution of total zooplankton.

Table 2 Density of zooplankton and percentage composition of various taxonomic groups at respective station in April, 1989.

Station	HO-11	12	13	14	15	16	1	2	3	4	21	22	23	5	O-3a	3b	O-4	O-5	O-6
Density of zoopl. ($\times 10^3/m^3$)	29.0	8.4	23.6	26.1	21.1	12.2	23.7	14.6	10.5	12.6	12.7	11.8	11.9	10.1	10.5	8.4	7.2	9.2	2.9
Composition of taxonomic groups																			
COPEPODA																			
Oithona	40.4	21.4	24.9	27.0	15.5	37.0	38.6	26.7	35.7	18.7	24.2	17.0	30.2	19.4	24.9	15.3	17.4	17.0	10.5
Paracalanus	2.5	10.1	1.5	0.5	0.5	5.4	2.1	8.5	15.1	12.7	10.4	8.3	10.1	13.5	21.0	18.8	17.5	14.2	4.8
Acartia	3.8	6.6	9.3	10.4	10.8	2.9	5.8	5.0	4.0	4.4	6.1	6.3	2.6	4.2	4.7	7.4	10.1	6.1	19.0
Oncaea	1.3	0.8	0.9	0.2	0.5	4.3	0.3	9.0	2.3	12.2	3.6	1.9	2.6	4.3	2.9	3.7	3.1	2.1	0.0
Corycaeus	0.9	2.7	0.7	0.0	0.2	2.3	1.3	4.5	5.7	11.1	7.4	7.2	8.3	9.1	7.0	7.0	8.1	12.3	2.8
Microsetella norvegica	0.4	1.3	0.3	0.0	0.3	1.8	0.3	13.2	4.4	6.8	5.6	4.1	5.3	4.6	3.2	2.4	3.8	3.3	0.4
Nauplii	9.0	2.9	20.9	18.8	17.7	19.7	14.8	8.5	15.5	13.8	15.4	16.1	17.6	24.0	28.4	28.4	24.6	24.5	27.0
Others	1.2	4.0	0.5	1.0	0.0	3.4	0.8	3.5	3.2	2.1	1.6	0.6	1.6	2.4	1.4	2.2	2.1	2.0	1.6
Total	59.6	59.8	58.9	57.7	45.6	76.9	64.1	79.0	86.0	81.9	74.6	61.5	78.1	81.5	93.4	85.3	86.7	81.6	66.1
OTHER ZOOPLANKTON																			
Evadne nordmanni	20.5	25.6	21.6	20.9	28.2	8.4	21.6	7.0	2.3	1.1	11.4	15.7	5.3	1.5	0.1	0.2	0.0	0.1	0.0
Balanid nauplii	3.9	2.5	3.6	1.8	1.9	2.0	1.0	2.8	1.7	3.6	1.0	3.0	2.2	2.5	0.3	1.1	1.3	3.6	1.3
Oikopleura dioica	2.2	2.3	1.6	1.0	4.1	2.5	2.1	2.0	3.9	7.3	7.2	4.8	3.0	3.8	1.9	4.8	5.0	12.5	17.7
Sagitta crassa	0.2	0.6	0.3	0.0	0.0	0.2	0.4	0.0	0.0	0.2	0.9	0.2	0.0	0.6	0.3	0.2	0.6	0.0	0.0
Polychaete larvae	0.6	1.1	0.5	3.7	4.1	0.7	1.7	0.5	0.3	0.2	0.3	0.4	0.6	0.2	1.0	0.2	0.6	0.3	2.4
Bivalve veligers	12.0	6.8	12.6	11.5	13.4	9.3	7.5	8.5	5.8	5.6	4.5	14.3	10.1	8.3	2.6	6.8	5.2	0.3	11.3
Others	1.0	1.3	0.9	3.5	2.6	0.0	1.7	0.2	0.1	0.2	0.2	0.1	0.8	1.6	0.3	1.3	0.7	1.6	0.9
Total	40.4	40.2	41.1	41.3	54.4	23.1	35.9	21.0	14.0	18.1	25.4	38.5	21.9	18.5	6.6	14.7	13.3	18.4	33.9

Table 3 Denisity of zooplankton and percentage composition of various taxonomic groups at respective station in July, 1989.

Station	HO-12	13	14	15	16	1	2	3	4	21	22	23	5	O-3a	3b	O-4	O-5	O-6
Density of zoopl. (×$10^3/m^3$)	46.2	42.9	174.5	41.0	15.2	53.0	22.5	21.1	16.0	23.0	39.2	11.6	13.5	15.0	15.3	26.8	14.6	3.1
Composition of taxonomic groups																		
COPEPODA																		
Oithona	80.0	67.7	73.1	39.6	47.1	32.0	48.4	26.3	18.0	33.2	16.4	13.6	15.2	18.4	15.8	6.5	8.3	9.1
Paracalanus	7.8	6.6	4.6	16.1	23.3	18.1	14.9	32.5	32.0	20.3	30.2	32.2	29.4	58.6	37.4	33.8	40.1	13.6
Acartia	0.2	2.8	4.0	6.9	6.1	11.6	3.9	6.9	10.5	5.9	5.2	6.4	8.6	9.1	8.8	12.2	11.4	11.6
Oncaea	0.9	0.1	0.0	0.8	0.9	2.7	8.4	3.0	3.6	8.3	3.8	5.3	13.1	8.3	6.9	1.4	0.8	0.0
Corycaeus	0.2	0.3	0.0	0.6	0.3	0.6	1.3	2.0	6.2	1.3	1.1	7.7	6.6	7.5	3.1	2.4	2.9	1.0
Microsetella norvegica	0.2	0.2	0.1	1.1	0.6	1.1	1.3	3.0	1.4	1.8	2.0	5.3	1.6	5.8	2.3	2.4	3.4	1.5
Nauplii	2.2	7.7	6.9	16.6	9.0	17.5	7.2	12.7	22.3	6.5	6.6	7.7	9.4	8.6	15.4	27.5	20.7	29.3
Others	0.8	0.2	0.0	0.8	1.2	1.2	1.1	1.0	0.3	1.8	1.2	0.5	1.1	1.2	0.5	0.4	1.4	29.8
Total	92.9	85.7	88.7	81.4	88.4	84.8	86.6	87.6	94.2	79.1	67.5	78.7	96.3	93.3	90.2	86.5	86.2	81.3
OTHER ZOOPLANKTON																		
Evadne nordmani	0.6	1.2	2.8	1.1	1.5	1.1	0.1	1.2	0.1	1.4	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Penilia avirostris	0.2	0.4	2.0	0.6	1.2	2.3	1.9	0.8	0.0	6.1	11.8	8.0	0.3	0.0	0.0	0.0	0.0	0.0
Balanid nauplii	0.6	1.3	0.0	2.7	0.6	1.0	2.0	0.2	1.1	1.4	0.2	0.3	0.0	0.5	0.1	1.4	2.1	3.1
Oikopleura dioica	4.3	6.0	2.4	6.4	5.5	3.6	2.1	5.4	1.9	9.4	15.3	10.1	0.6	0.7	2.3	2.2	4.5	9.1
Sagitta crassa	0.2	0.7	0.0	0.6	0.9	0.0	0.7	1.2	0.1	0.9	2.0	0.8	1.0	1.1	0.1	0.3	0.3	0.0
Polychaete larvae	0.0	3.5	3.6	7.2	0.6	6.8	1.1	0.5	0.6	0.4	0.9	0.5	0.2	0.3	1.4	0.4	0.8	1.5
Others	1.2	2.8	0.5	0.0	1.3	0.4	5.5	3.1	2.0	1.3	2.1	0.8	1.6	4.1	5.9	9.2	6.1	5.0
Total	7.1	14.3	11.3	18.6	11.6	15.2	13.4	12.4	5.8	20.9	32.5	21.3	3.7	6.7	9.8	13.5	13.8	18.7

Table 4 Density of zooplankton and percentage composition of various taxonomic groups at respective station in September, 1989.

Station	HO-11	12	13	14	15	16	1	2	3	4	21	22	23	5	O-3a	3b	O-4	O-5	O-6
Density of zoopl. ($\times 10^3/m^3$)	53.0	25.4	84.7	83.9	65.0	64.5	80.1	71.5	47.5	32.2	106.8	92.5	30.1	38.4	36.9	22.4	27.0	20.6	12.7
Composition of taxonomic groups																			
COPEPODA																			
Oithona	66.1	46.9	46.0	46.4	20.2	65.8	17.4	24.5	7.2	8.2	2.9	3.7	10.7	13.5	9.7	21.7	15.7	38.7	85.0
Paracalanus	7.1	4.1	11.5	8.7	8.7	5.3	8.4	8.7	9.2	14.0	4.4	6.4	8.4	9.5	11.7	6.9	4.0	6.2	1.6
Acartia	1.0	0.7	1.1	1.5	0.7	2.2	3.5	1.4	4.7	2.0	4.6	3.5	1.7	4.8	1.0	6.2	3.3	4.5	3.7
Oncaea	2.0	10.0	4.3	1.5	35.0	5.0	8.6	19.0	9.7	19.9	6.5	7.8	34.8	11.0	16.9	6.4	5.2	1.2	0.4
Corycaeus	0.3	0.4	0.1	0.4	0.4	0.1	0.4	0.7	1.2	0.7	1.1	0.7	0.3	0.8	1.2	0.5	0.9	0.5	0.0
Microsetella norvegica	0.9	4.7	9.0	2.7	6.4	3.7	12.2	21.0	31.4	26.4	38.0	43.9	22.5	43.1	34.0	35.3	55.0	31.4	0.4
Nauplii	6.9	12.5	10.2	23.8	12.6	6.4	26.1	11.4	19.3	12.2	22.2	10.5	5.9	7.1	12.6	12.8	9.7	10.1	5.7
Others	1.1	2.4	1.7	4.0	1.1	0.6	2.8	2.3	1.9	2.3	1.2	1.0	1.5	1.9	1.1	2.3	1.6	1.2	1.2
Total	85.4	81.7	83.9	89.0	85.1	89.1	79.4	88.3	84.6	85.7	80.9	77.5	85.8	91.7	88.2	92.1	95.4	93.8	98.0
OTHER ZOOPLANKTON																			
Evadne tergestina	0.3	0.5	0.4	0.3	0.4	0.2	1.3	0.8	0.9	0.0	1.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Penilia avirostris	0.6	0.4	2.5	1.1	2.1	1.2	3.0	2.7	4.9	1.0	10.9	16.7	2.3	0.0	3.8	0.0	0.0	0.0	0.0
Balanid nauplii	0.5	0.9	0.5	0.9	0.7	0.4	0.7	0.2	0.7	0.0	0.0	0.1	0.4	0.0	0.3	0.2	0.0	0.0	0.4
Oikopleura dioica	9.8	11.6	6.8	4.3	3.3	4.8	8.6	3.5	2.9	6.0	2.2	2.6	5.7	1.5	2.8	1.7	1.3	1.7	0.4
Sagitta crassa	0.3	0.2	0.2	0.0	0.1	0.5	0.2	0.6	0.7	1.0	0.7	0.5	1.4	0.2	0.6	0.5	1.0	0.7	0.4
Polychaete larvae	1.2	0.4	1.2	0.6	1.7	0.8	1.6	0.8	0.5	2.2	0.3	0.5	2.5	1.7	1.6	2.2	1.6	1.0	0.4
Others	1.9	4.3	4.5	3.8	6.6	3.0	5.2	3.1	4.8	4.1	3.6	1.2	1.9	4.9	2.7	3.3	0.7	2.8	0.4
Total	14.6	18.3	16.1	11.0	14.9	10.9	20.6	11.7	15.4	14.3	19.1	22.5	14.2	8.3	11.8	7.9	4.6	6.2	2.0

Table 5 Density of zooplankton and percentage composition of various taxonomic groups at respective station in December, 1989.

Station	HO-11	12	13	14	15	16	1	2	3	4	21	22	23	5	O-3a	3b	O-4	O-5	O-6
Density of zoopl. ($\times 10^3/m^3$)	9.8	7.7	8.4	22.0	11.8	8.0	16.7	24.7	7.6	11.1	18.5	21.0	22.3	19.4	11.1	12.8	6.6	4.8	9.1
Composition of taxonomic groups																			
COPEPODA																			
Oithona	33.9	17.4	47.1	63.8	16.9	31.2	32.3	19.6	18.4	11.6	19.6	14.9	8.6	11.4	7.7	4.0	6.4	10.8	12.1
Paracalanus	18.7	14.0	15.6	13.2	20.2	26.1	16.7	21.2	21.7	6.6	11.6	14.6	10.9	8.1	17.5	9.6	21.1	31.3	22.9
Acartia	0.2	0.0	0.4	0.2	0.3	0.0	0.0	0.1	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.6	1.7
Oncaea	13.8	31.7	13.3	0.0	24.2	15.8	8.2	11.4	26.6	45.1	30.4	43.1	29.3	40.9	38.7	37.3	27.5	14.2	10.4
Corycaeus	1.6	2.0	0.4	0.0	0.3	0.4	0.4	0.0	2.2	5.6	1.7	1.0	2.4	3.1	3.2	2.2	2.0	2.0	0.9
Microsetella norvegica	0.0	3.8	0.0	0.0	12.6	3.6	0.0	3.8	10.4	8.7	2.9	4.5	28.5	16.7	13.3	39.8	31.2	23.1	31.2
Nauplii	14.4	11.9	10.3	9.7	11.6	11.9	20.7	30.3	9.8	12.2	20.0	11.0	8.9	9.9	8.3	2.0	6.1	8.0	10.4
Others	4.5	5.8	3.0	3.3	4.6	3.2	1.4	1.5	1.1	0.3	3.5	4.3	2.7	3.0	0.9	0.5	1.4	2.8	1.3
Total	87.2	86.6	90.1	90.1	90.7	92.1	79.6	87.9	90.4	90.1	89.9	93.5	91.3	93.2	89.6	95.8	95.7	92.9	90.9
OTHER ZOOPLANKTON																			
Balanid nauplii	0.0	0.3	1.5	1.9	2.0	0.0	6.7	1.2	1.4	0.7	0.6	0.0	1.3	1.4	1.8	0.5	0.3	0.6	1.7
Oikopleura dioica	10.2	9.0	6.5	7.0	4.0	7.5	12.2	8.7	4.0	7.5	2.9	4.0	5.4	2.3	2.0	1.5	1.2	4.3	1.3
Sagitta crassa	0.0	0.6	1.1	0.0	1.7	0.0	0.7	0.7	0.8	0.3	1.0	0.9	0.5	0.3	0.7	0.2	0.0	0.3	0.0
Polychaete larvae	1.4	1.5	0.4	0.2	1.0	0.0	0.2	1.5	3.3	1.2	2.7	1.7	0.8	1.1	1.5	0.5	0.9	0.6	1.7
Others	1.2	2.0	0.4	0.8	0.6	0.4	0.6	0.0	0.0	0.2	2.9	0.0	1.7	1.6	4.5	1.5	2.0	1.4	4.4
Total	12.8	13.4	9.9	9.9	9.3	7.9	20.4	12.1	9.6	9.9	10.1	6.5	8.7	6.8	10.4	4.2	4.3	7.1	9.1

Bay; the density was highest ($101x10^3$ indiv. m^{-3}) at Stn. HO-21. In contrast, the density was low ($12-19x10^3$ indiv. m^{-3}) at Stns. O-5 and 6 in Akitsu Bay. Copepods constituted at least 77.8% (mean: 87.1%) of the total zooplankton. *Oithona*, *Microsetella norvegica*, *Oncaea* and nauplii were numerically important groups (Table 4). In the other zooplankton, a larvacean *O. dioica* occurred abundantly at many stations and a cladoceran *Penilia avirostris* occurred numerously at some stations (e.g. Stns. HO-21 and 22).

Overall mean zooplankton density was lowest in December as well as in April. The density was high at Stns. HO-2, 14, 22 and 23 ($21-25x10^3$ indiv. m^{-3}), but extremely low at Stn. 0-5 ($4.8x10^3$ indiv. m^{-3}). On average, 90.1% of the zooplankton was consisted of copepods. Among these, *Oithona, Paracalanus, Oncaea, M. norvegica* and nauplii were abundant. Following copepods, a larvacean *O. dioica* was numerically important (Table 5).

2. Copepods

Oithona (Fig. 4)

Although there were several species belonging to the genus *Oithona* in this study, it was impossible to identify to the species level for copepodite stages. Within the genus *Oithona, O. davisae* was most abundant throughout the year. *O, similis*, which is larger than *O. davisae*, was relatively important in cold seasons and at offshore stations. The abundance of the genus *Oithona* was always high in the innermost part of Hiroshima Bay, being more conspicuous in July and September, when it comprised more than 66 and 40% of the total zooplankton, respectively. The annual highest density ($122x10^3$ indiv. m^{-3}) was recorded at Stn. HO-14 in July. The occurrence was usually scarce in the southern part of Hiroshima Bay (south of Miyajima Seto), Aki Nada and Akitsu Bay. However, $10.8x10^3$ indiv. m^{-3} of *Oithona* occurred at Stn. O-6 in September.

Paracalanus (Fig. 5)

Probably only one species of *Paracalanus*, which we call tentatively *Paracalanus* sp., occurred in our study area. This species had been referred formerly to *P. parvus* by many workers (e.g. HIROTA, 1964, 1979) but is morphologically more similar to *P. quasimodo* (J. HIROMI, personal comm.). *Paracalanus* was distributed rather homogeneously over the study area. Seasonally, the density was higher in warm seasons (July and September) than in cold seasons (April and December). The highest density ($12x10^3$ indiv. m^{-3}) was recorded at Stn. HO-22 in July.

Acartia (Fig. 6)

A cold-water species, *Acartia omorii*, appeared in the plankton in April, July and December, and two warm-water forms, *A. erythraea* and *A. pacifica*, occurred in September. However, their copepodite stages could not be identified to respective species and they were treated as the generic level. *Acartia* was most abundant in the northern Hiroshima Bay in April, but it tended to be distributed more homogeneously over the study area in July. In September, the abundance was highest at Stns. HO-21 and 22. There were few *Acartia* in December. The highest density ($6.9x10^3$ indiv. m^{-3}) was recorded at Stn. 14 in July.

Oncaea (Fig. 7)

Oncaea media was the only species that we could identify for adult stage. This genus did not show any particular geographical distribution. However, it did not occur at Stn.

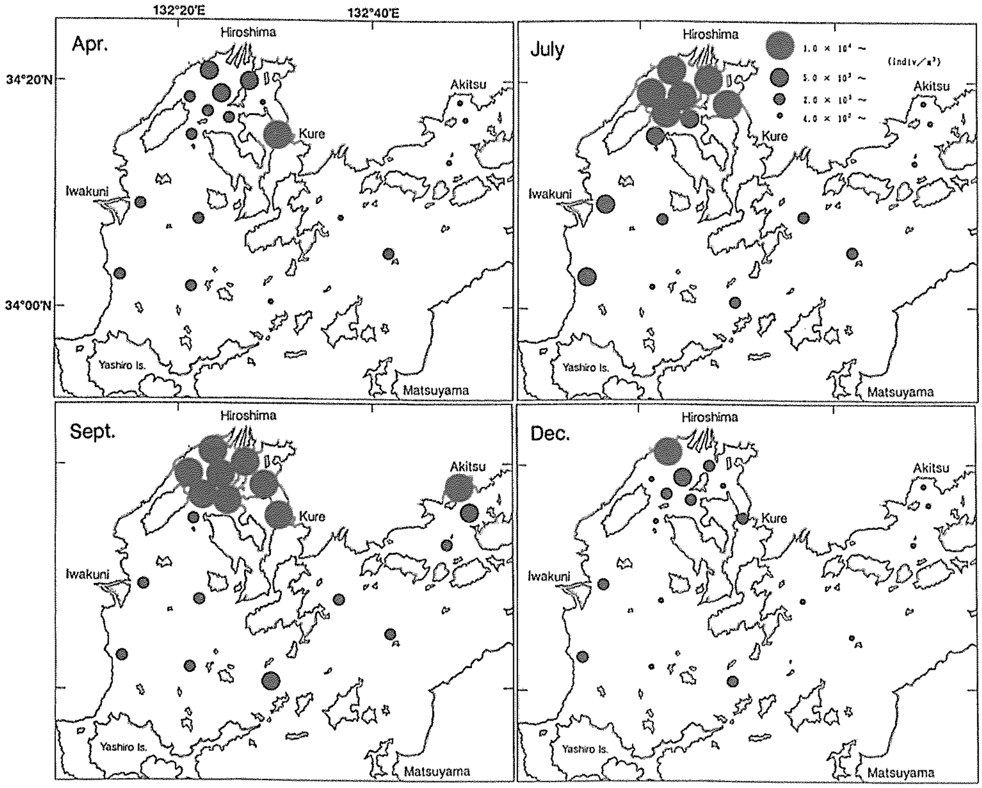

Fig. 4 Geographical distribution of *Oithona*.

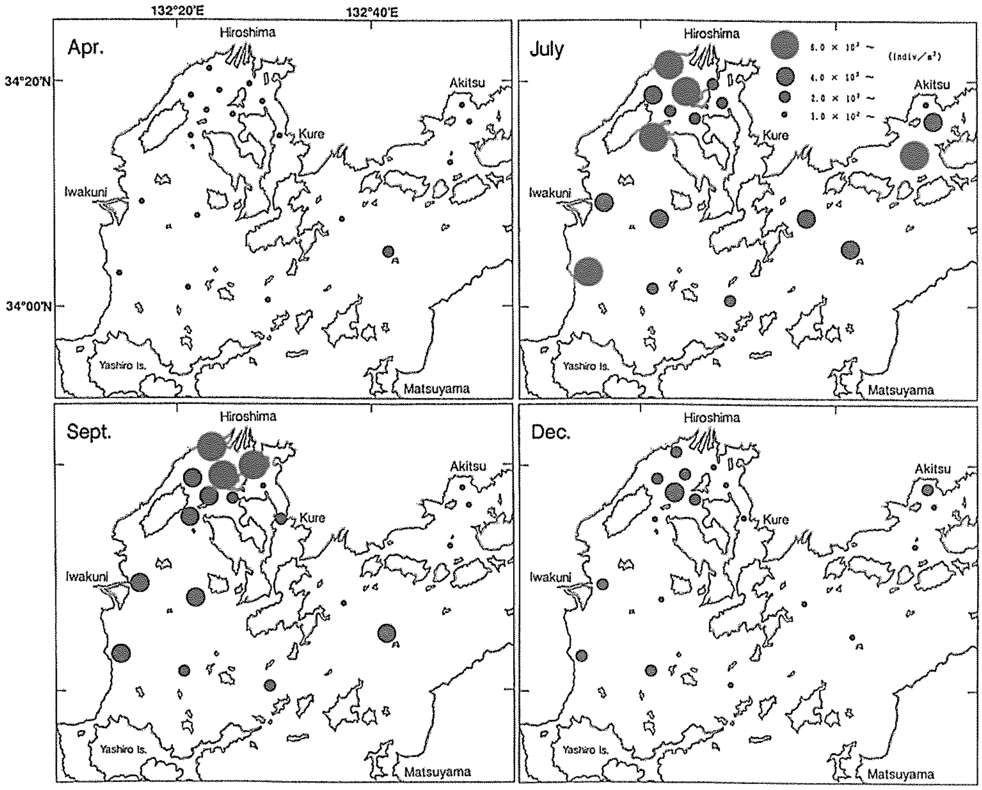

Fig. 5 Geographical distribution of *Paracalanus*.

HO-14 in July and December, probably due to low salinity at this station. The overall density was highest in September, when more than 10x10^3 indiv. m^{-3} appeared at Stns. HO-2, 15 and 23, and was followed by December. The density was lowest in April.

Corycaeus (Fig. 8)

Although several species were probably included in the genus *Corycaeus*, *C. affinis* was the most abundant species. The occurrence of this genus neither showed remarkable seasonal nor geographical variation. However, as found for *Oncaea*, no *Corycaeus* occurred occasionally at Stn. HO-14 (HO-2, also in December).

Microsetella norvegica (Fig. 9)

This long-bodied harpacticoid was easy to identify even in copepodite stages. The overall density of this species was low in April and July, but increased remarkably in September, when the density was highest (41x10^3 indiv. m^{-3}) at Stns. HO-21 and 22. The population density decreased in December. Judging from its geographical distribution, this species avoided less saline area, e.g. at Stn. HO-14.

Nauplii (Fig. 10)

The density of copepod nauplii was highly underestimated due to passage of nauplii through the mesh opening (96 μm) of the plankton net. They were nearly homogeneously distributed over the study area in April and December, but in July and September they tended to be more abundant in the northern Hiroshima Bay. The most of nauplii collected in this area were identified as *Oithona*. The highest density of nauplii (24x10^3 indiv. m^{-3}) was recorded at Stn. 21 in September.

3. Balanid nauplii (Fig. 11)

In general, balanid nauplii were distributed more abundantly in the innermost part of Hiroshima Bay, although at some stations they were not found in the sample. The highest density recorded was 1.2x10^3 indiv. m^{-3} at Stn. 11 in April. The numerical abundance did not show any apparent seasonal variation.

4. Bivalve veligers (Fig. 12)

Bivalve veligers were more abundant in April and September than in July and December. Geographically, they tended to be distributed more abundantly in the northern Hiroshima Bay, especially in April and September. The highest density (3.9x10^3 indiv. m^{-3}) was recorded at Stns. HO-1 and 15 in September.

5. *Oikopleura dioica* (Fig. 13)

A larvacean *Oikopleura dioica* was more abundant in warm months (July and September) than in cold months (April and December). Although it occurred nearly homogeneously in April, it tended to be more abundant in Hiroshima Bay than in Aki Nada and Akitsu Bay in July, September and December. The highest density (6.9x10^3 indiv. m^{-3}) was recorded at Stn. HO-1 in September.

6. Polychaete larvae (Fig. 14)

The area of high density of polychaete larvae was confined to the innermost part of Hiroshima Bay in April and July. In September, however, the overall density increased and the geographical distribution was more homogeneous. In December, the density decreased. The highest density was 6.2x10^3 indiv. m^{-3} at Stn. HO-14 in July.

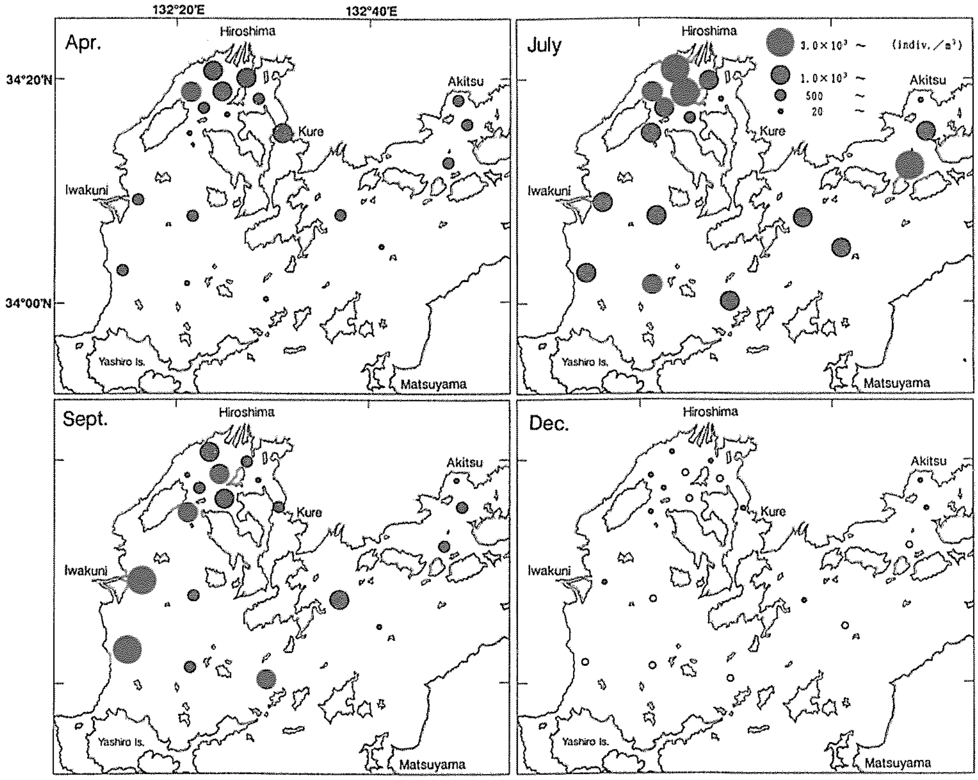

Fig. 6 Geographical distribution of *Acartia*.

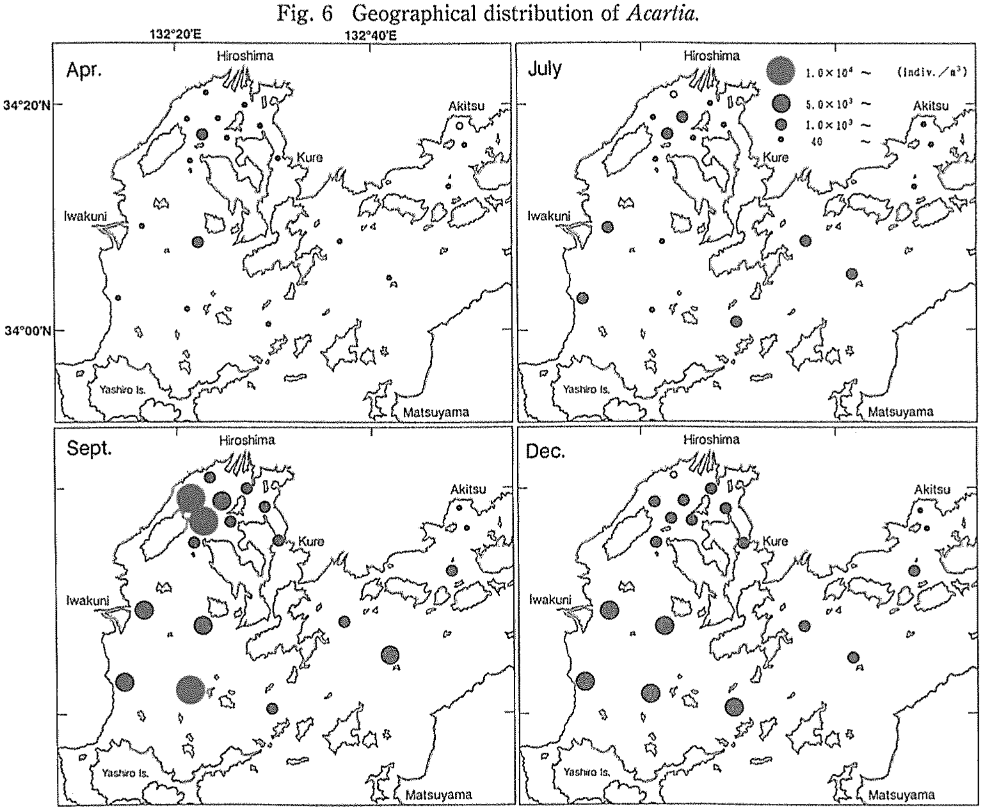

Fig. 7 Geographical distribution of *Oncaea*.

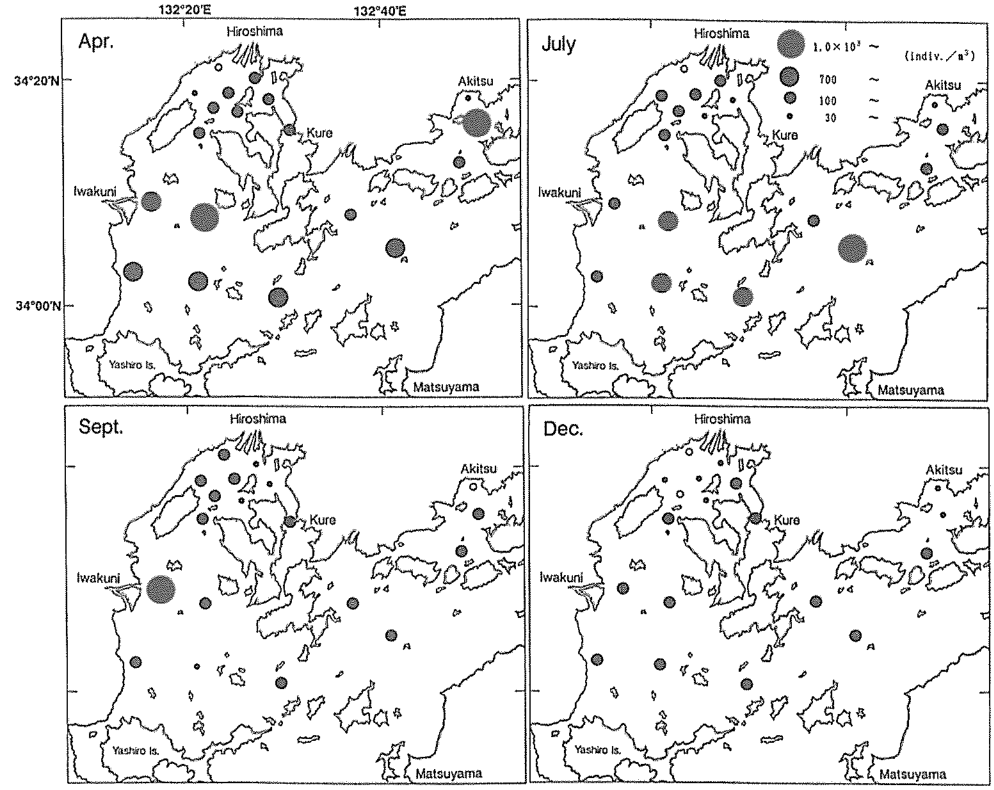

Fig. 8 Geographical distribution of *Corycaeus*.

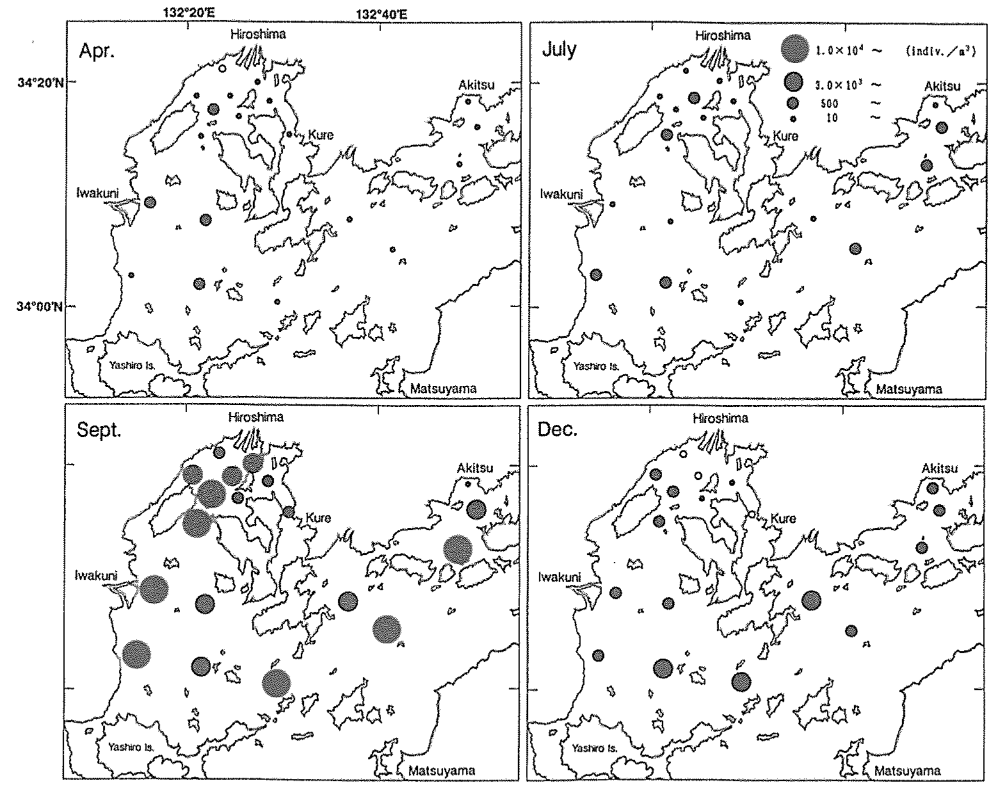

Fig. 9 Geographical distribution of *Microsetella norvegica*.

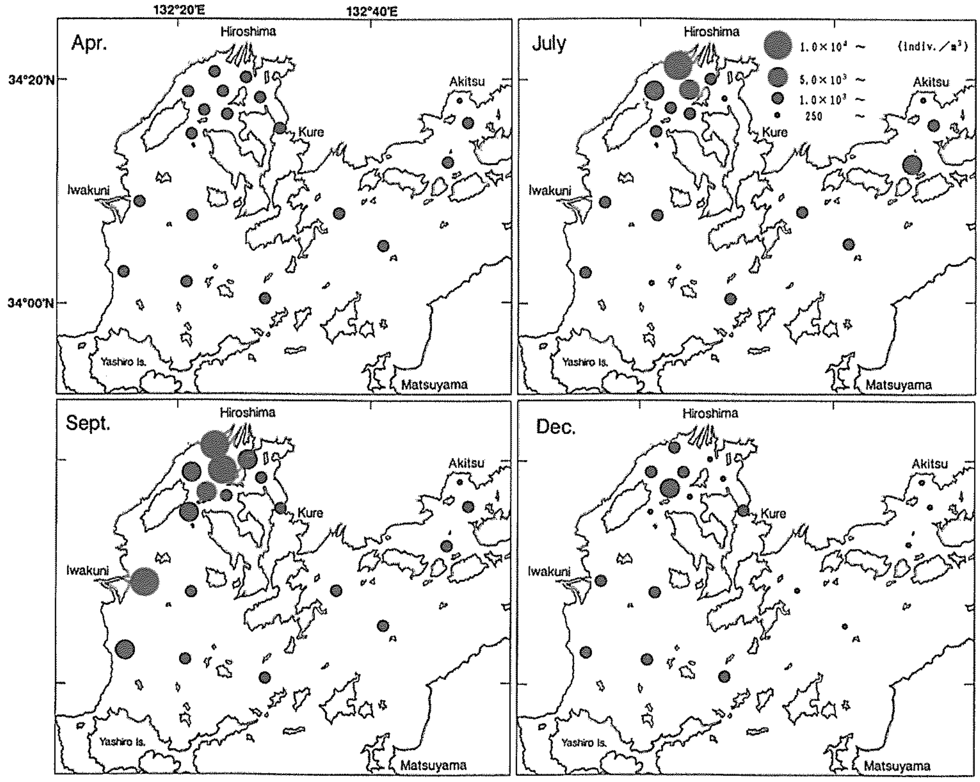

Fig. 10 Geographical distribution of copepod nauplii.

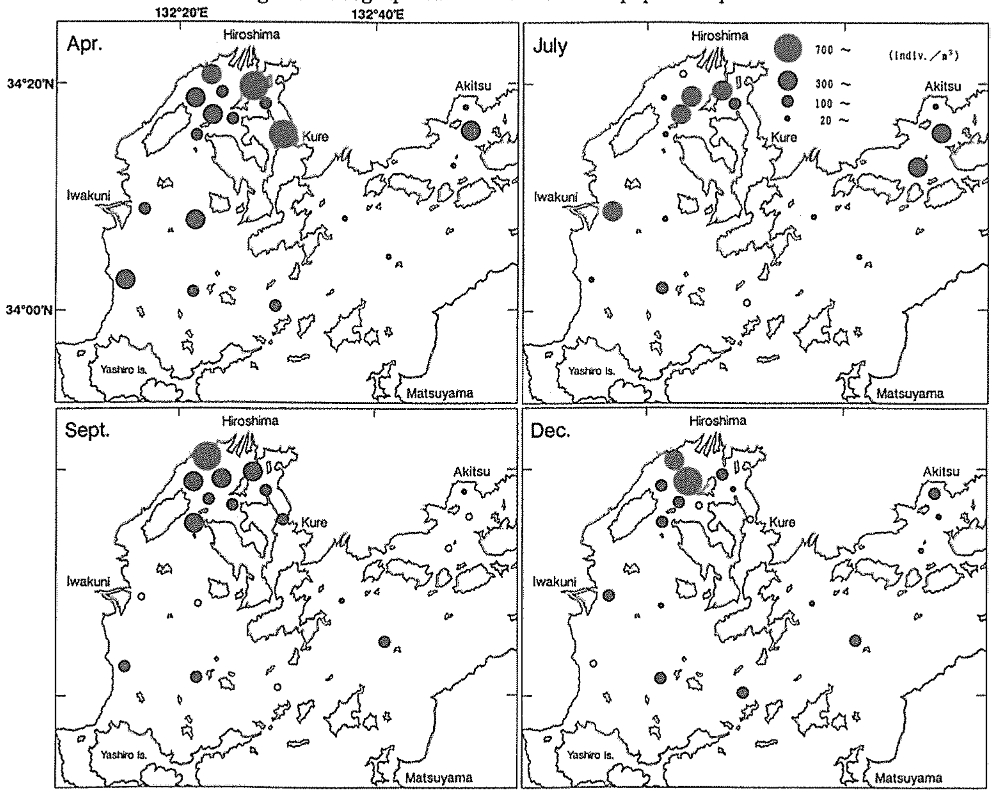

Fig. 11 Geographical distribution of balanid nauplii.

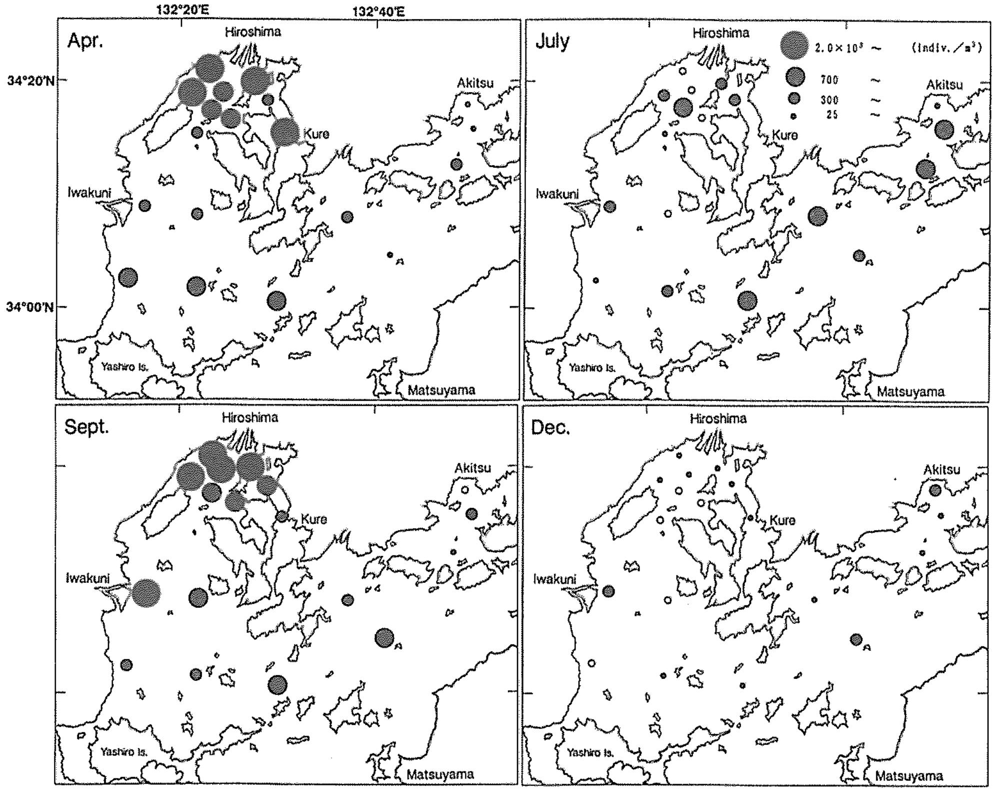

Fig. 12 Geographical distribution of bivalve veligers.

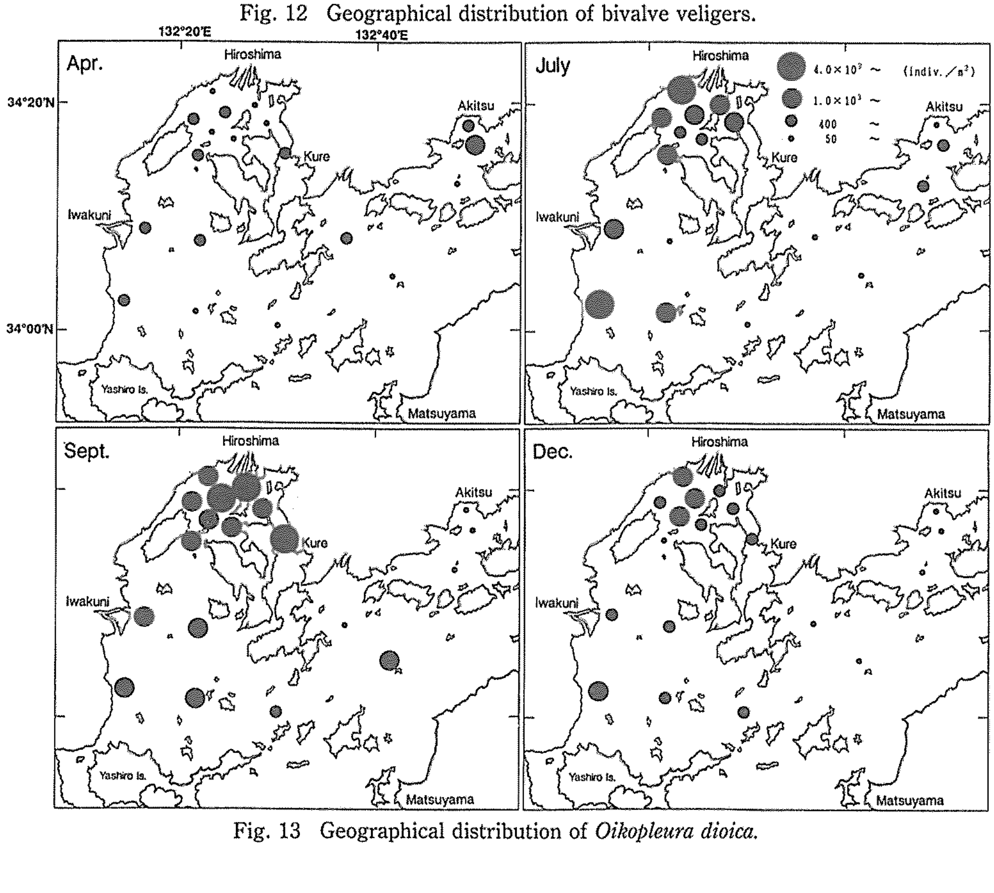

Fig. 13 Geographical distribution of *Oikopleura dioica*.

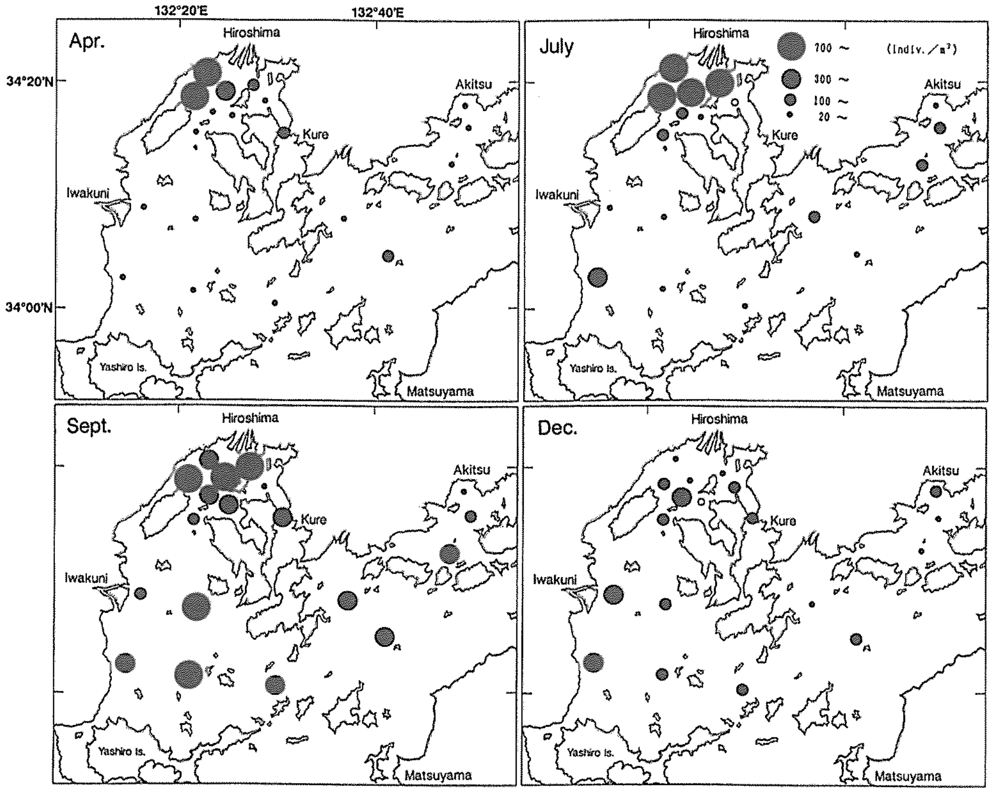

Fig. 14 Geographical distribution of polychaete larvae.

7. Other zooplankton

Copepods, which appeared in the study area in small numbers and hence were not mentioned above, included *Calanus sinicus*, *Centropages abdominalis*, *C. tenuiremis*, *Euterpina acutifrons*, *Temora turbinata*, *Tortanus forcipatus*, *T. gracilis*, and the genera of *Clytemnestra* and *Euchaeta*. *Calanus sinicus* occurred at low densities (< 400 indiv. m^{-3}) throughout the year mainly in the southern part of Hiroshima Bay. *Centropages abdominalis* occurred in December and April in the northern Hiroshima Bay. On the contrary, *Centropages tenuiremis* appeared in September over the entire Hiroshima Bay. *E. acutifrons* was present from July to December in the southern Hiroshima Bay. The genera of *Clytemnestra*, *Euchaeta*, *Temore* and *Tortanus* occurred sporadically in the southern Hiroshima Bay and Aki Nada.

Five species of cladocerans were identified: *Evadne nordmanni*, *E. tergestina*, *Penilia avirostris*, *Podon leuckarti* and *P. polyphemoides*. Their density was usually highest in the northern Hiroshima Bay, except for *Penilia avirostris* which was distributed mainly in the southern Hiroshima Bay in July and September. *E. nordmanni* occurred in April and July, and *E. tergestina* appeared in July and September. Two species of *Podon* occurred in April and July.

A chaetognath *Sagitta crassa*, crab zoeae and shrimp mysis were present throughout the year over the entire study area.

DISCUSSION

Based on the hydrographic conditions, our study area can be divided into four regions, i.e. the northern (or innermost part) Hiroshima Bay, the southern Hiroshima Bay, Aki Nada and Akitsu Bay. The northern Hiroshima Bay is surrounded by three large islands (Itsuku Island, Nomi Island and Eta Island) on the south and characterized a eutrophic embayment by the effect of discharge mainly from Ohta River (YUASA *et al.*, 1984). In this region, phytoplankton standing stock was always high. The southern Hiroshima Bay is an open water area. Offshore water from Iyo Nada inflows northward along the western coast of Kurahashi Island and Nomi Island, and nutrient-rich water from the northern Hiroshima Bay and directly discharged from rivers on the west coast of Hiroshima Bay flows southward along the west coast of the Bay, forming an anticlockwise eddy in the central part of southern Hiroshima Bay (UESHIMA *et al.*, 1981). Nutrient-rich water is moderately diluted here with offshore water. The effect of offshore water from Iyo Nada is strongest in Aki Nada, since the connection between Aki Nada and Iyo Nada is close. Chlorophyll concentration was always lowest in this region. Akitsu Bay is surrounded by several islands on the south and receives the discharge from rivers, although they are small. Due to strong tidal current, phytoplankton biomass was as low as Aki Nada.

From the results of the present investigation, it was apparent that the numerical abundance of total zooplankton was highest in the northern Hiroshima Bay, followed in order by southern Hiroshima Bay, Aki Nada and Akitsu Bay. Although many factors can be related to the above-mentioned geographical distribution, food supply might be the most important factor. Hence, the total zooplankton density was plotted against chlorophyll concentration, an indicator of the amount of food for herbivorous zooplankton (Fig. 15). A significantly ($p<0.01$) positive relationship was detected, which was expressed by

$$Z=9812+4370P \quad (r=0.51)$$

where Z is total zooplankton abundance (indiv. m^{-3}) and P is chlorophyll concentration ($\mu g\ l^{-1}$).

Among zooplankton, copepods were the dominant constituents (overall mean: 83%). Among copepods, *Oithona* was most abundant throughout the year, in particular in northern Hiroshima Bay. Hence, a significantly ($p<0.01$) positive relationship was obtained between natural logarithm of *Oithona* abundance (Zo, indiv. m^{-3}) and chlorophyll concentration (Fig. 15):

$$\ln Zo=7.416+0.225P \quad (r=0.61).$$

No such a significant relationship was found for copepods other than *Oithona*. *Paracalanus* was the second important copepod, being distributed over the entire study area, especially in warm seasons. *Acartia omorii* was abundant in northern Hiroshima Bay in April. *Oncaea* and *Microsetella norvegica* were relatively important in southern Hiroshima Bay and Aki Nada.

Oithona, both *O. davisae* (formerly referred to *O. nana*) and *O. similis*, *Paracalanus* sp. (formerly referred to *P. parvus*), *Acartia omorii* (formerly referred to *A. clausi*), the genus *On-*

caea and *Microsetella norvegica* were used, based on their regional distributions, by YAMAZI (1952) and HIROTA (1968) as indicator species for the hydrographic condition of the water mass. According to the regional distributions of the copepods listed above in October, 1951, YAMAZI (1952) reported that the northern Hiroshima Bay was divided into three areas, i.e. *Acartia omorii* area, *Paracalanus sp.-Oithona davisae* area and *Paracalanus* sp.-*Oithona similis* area, toward offshore. HIROTA (1968) reported, based on the species composition at two stations in southern Hiroshima Bay, in June, 1963, that the area was dominated by *Paracalanus* sp. and *Oithona similis*. The regional distribution of the dominant copepods obtained in our investigation was generally the same as the previous results. Although the water has been eutrophicated considerably in recent 30-40 years in Hiroshima Bay, the regional distribution pattern of the dominant copepods has not changed notably.

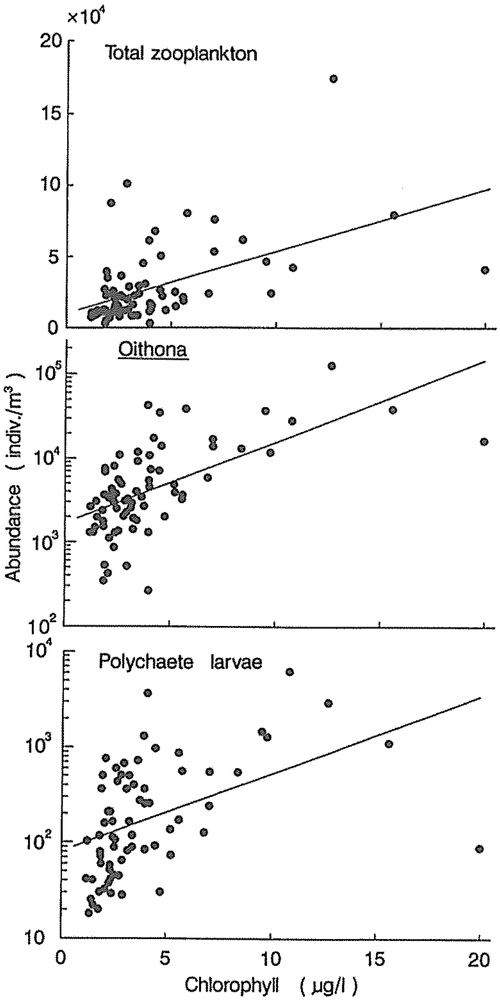

Fig. 15 Relationship between chlorophyll concentration and the density of total zooplankton (top), *Oithona* (middle) and polychaete larvae (bottom). Note the difference of the scale of zooplankton numerical abundance.

KADO (1954) reported that the warm oceanic copepods (e.g. *Eucalanus attenuatus*, *E. mucronatus*, *E. subcrassus*, *Acrocalanus gracilis* and *Temora turbinata*) and chaetognaths (e.g. *Sagitta enflata*, *S. bedoti* and *S. minima*) occurred in Hiroshima Bay in fall. He did not show the density of these organisms and hence the quantitative comparison is impossible. However, our samples contained few of these oceanic species. *T. turbinata* was found at several stations in southern Hiroshima Bay (the maximum density was 220 indiv. m^{-3}). Neither *Eucalanus* nor *S. enflata* were found in our samples. Although the occurrence of these oceanic zooplankton depends on the transport of the warm water mass from Bungo Channel, the very few occurrence of them may indicate that Hiroshima Bay is no longer the area for their seasonal habitation.

The geographical distribution of zooplankton other than copepods was roughly the same as observed for copepods. A larvacean *Oikopleura dioica* and larval plankton (balanids, bivalves and polychaetes) were distributed abundantly in northern Hiroshima Bay. A following positive ($p<0.01$) relationship was observed between polychaete larvae density (*Zp*, indiv. m^{-3}) and chlorophyll concentration (Fig. 15):

$$\ln Zp = 4.381 + 0.188P \quad (r=0.46).$$

Regarding the anchovy fisheries in the study area, adult anchovy migrate into the northern Hiroshima Bay and some of them are caught commercially by boat seine. However, according to the empirical observations by fishermen, larval anchovy (locally called as "shirasu") hardly migrate into this region, and hence the commercial boat seine is operated usually in southern Hiroshima Bay and Aki Nada. Our unpublished data show that *Paracalanus*, *Corycaeus*, *Oncaea* and balanid nauplii are important food for larval anchovy, although *Oithona* and *M. norvegica* are hardly eaten by them. In spite of the high numerical abundance (probably the high production rate, too), *Oithona* in the northern Hiroshima Bay may not be utilized efficiently by planktivorous fish.

Acknowledgments We would like to thank the captain and crew of T&R/V *Toyoshio Maru* for assistance in the sampling at sea. Gratitude is extended to Dr. S. Ohtsuka for help in the indenitfication of zooplankton.

REFERENCES

HADA, Y., 1974, The Flagellata examined from polluted water of the Inland Sea, Setonaikai. *Bull. Plankton Soc. Japan,* 20: 112-125.

HIROSHIMA PREFECTURAL STATISTICS OFFICE, 1990, Hiroshima nourin suisan toukei nenpo (Annual Report on Agricultural and Fisheries Products in Hiroshima Prefecture), pp. 288-300. (In Japanese)

HIROTA, R., 1964, Zooplankton investigation in Hiuchi-nada in the Setonaikai (Inland Sea o Japan). I. The seasonal occurrence of copepods at the three stations in Hiuchi-nada. *J. Oceanogr. Soc. Japan,* 20: 24-31.

HIROTA, R., 1968, Zooplankton investigations in the Setonaikai (Inland Sea of Japan), I. Occurrence of zooplankton in the western half of the Setonaikai in June, 1963. *J. Oceanogr. Soc. Japan,* 24: 203-211.

HIROTA, R., 1979, Seasonal occurrence of zooplankton at a definite station off Mukaishima from July of 1976 to June of 1977. *Publ. Amakusa Mar. Biol. Lab., Kyushu Univ.,* 5: 9-17.

KADO, Y., 1954, The seasonal change of the chaetognath and pelagic copepod fauna of Hiroshima Bay in the Inland Sea of Japan, with special references to the appearance of oceanic species. *J. Sci., Hiroshima Univ., Ser. B, Div. 1,* 17: 121-129.

STRICKLAND, J. D. H. and T. R. PARSONS, 1972, A practical handbook of seawater analysis. *Bull. Fish. Res. Bd Can.,* 167: 1-310.

UESHIMA, H., E. HASHIMOTO and M. YAMAZAKI, 1981, On the similarity of dispersion in the hydraulic model based on river water discharge runs. *Govern. Indust. Res. Inst., Chugoku,* 14: 79-108. (In Japanese with English abstract)

UYE, S. and T. YAMAOKA, 1990, Vertical and horizontal distribution of copepod nauplii as food for anchovy larvae (*Engraulis japonica*) in Hiroshima Bay. *Bull. Japan. Soc. Fish. Oceanogr.,* 54: 341-351. (In Japanese with English abstract)

YUASA, I., H. UESHIMA, M. TAKARADA and E. HASHIMOTO, 1984, Characteristics of water quality in Hiroshima Bay and Kure Bay. *Govern. Indust. Res. Inst., Chugoku,* 22: 47-66. (In Japanese with English abstract)

広島湾とその周辺海域における動物プランクトンの地理的分布

上　真一・綾木　陽一・遠部　卓

広島大学生物生産学部，東広島市 724

1989年4月，7月，9月，12月の4回にわたり、広島湾、安芸灘，安芸津湾において動物プランクトンの地理的分布を調査した。動物プランクトン総個体密度は富栄養化の程度が最も激しい広島湾北部海域で周年高く，次いで広島湾南部海域，安芸灘，安芸津湾の順で低下した。動物プランクトン総個体密度とクロロフィル濃度との間には有意な正相関が観察された。動物プランクトンのうちカイアシ類が最も優占し，全体の50－98%（平均：83%）を占めた。カイアシ類の中では*Oithona* 属が最も多く，特に広島湾北部海域で非常に高い密度で出現した。*Paracalanus* 属は調査海域全体に比較的均一に分布し、*Oncaea* 属，*Microsetella norvegica* は広島湾南部海域を中心に出現した。今回観察されたこれらの主要カイアシ類の地理的分布パターンは，広島湾の富栄養化がそれほど顕著でない30－40年前の調査結果とほぼ同様であった。しかし以前は普通に観察されていた外洋性動物プランクトンの出現は希少であった。
キーワード：動物プランクトン，地理的分布，富栄養化，広島湾