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Seasonal Cycles in Abundance of Major Holozooplankton in the Innermost Part of Onagawa Bay, Northeast Japan*

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(Figs. 1–5)

INTRODUCTION

Some 30 years ago, YAMAZI (1953)[1] performed plankton investigations in Onagawa Bay for the first time by studying the composition and distribution of some important phyto- and zooplankton. As no further investigations have been conducted since then, our knowledge of the seasonal changes of the plankton community in this bay was totally inadequate. The importance of zooplankton from the viewpoint of biological production in the sea is generally recognized, but informations on the life history are yet incomplete for many zooplankton species. Studies of the seasonal cycles are necessary in order to determine the breeding seasons and the environmental factors that induce the population growth of the respective species. This paper intends to report the results of quantitative and qualitative surveys of the major holozooplankton carried out in the innermost part of Onagawa Bay during a 2 year period.

Onagawa Bay (38°25'N, 141°30'E) is the southernmost large indentation of the coast along Sanriku District, northeast mainland of Japan (Fig. 1). The bay is characterized by a steep decline of the slope to the basin which is deeper than 20 m. It is about 3 km across from north to south and 6.5 km from east to west. It opens to the Pacific Ocean by a wide mouth of ca. 4 km. The innermost part of the bay, Onagawa Harbor, is separated from the main basin by breakwaters jutting out from both sides of the constricted part of the harbor entrance. Although there is no significant inflow of freshwater into the bay, nutrient-rich waste water from nearby fish-processing companies is discharged, which causes somewhat eutrophic conditions.

MATERIALS AND METHODS

A single station was established in the innermost part of Onagawa Bay (Fig. 1), where the depth varied from 13.5 to 16.0 m depending on the state of the tide. For hydrographic measurements, the seawater was taken by means of a water sampler at depths of 1 and 10 m. Temperature readings were made with a hand-held thermometer, and the salinity was determined by Mohr's silver titration method. Zooplankton was collected by vertical tows from the bottom to the surface with a 0.225 m net (197 μm mesh size). This operation was performed usually in the morning (9:00–11:00 local time) at intervals

* The present research was made at the Onagawa Marine Laboratory when the author was affiliated to Tohoku University.

of approximately 2 weeks during 2 years between 9 June, 1976 and 21 May, 1978. Replicate or triplicate samples were taken on each sampling occasion and immediately preserved in 5% formalin-seawater solution. At the time of sampling, care was taken to let the net mouth rest upon the sea-bottom before hauling up. These samples were combined and appropriately split in order to identify the species. A minimum of several hundreds animals were counted under a dissecting microscope. The volume of water filtered was calculated from the flowmeter reading.

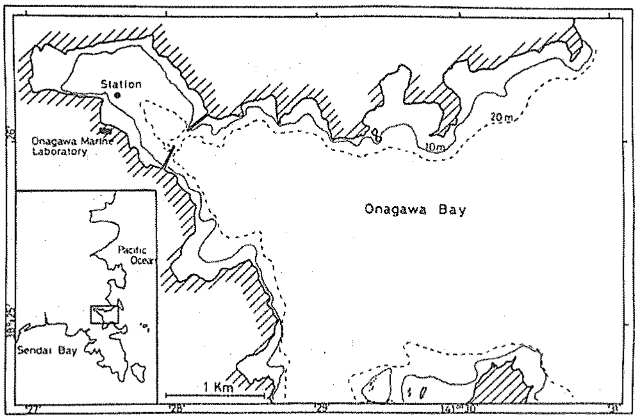

Fig. 1. Map of Onagawa Bay showing the location of the sampling station. The location of Onagawa Bay on the base of Oshika Peninsula in Miyagi Prefecture is shown in the inset.

RESULTS

VARIATION IN TEMPERATURE AND SALINITY (Fig. 2)

In the spring and summer, a thermal stratification was apparent, while in other seasons the water temperature was vertically homogeneous. The highest yearly temperatures were 21.6°C on 8 September, 1976 and 23.2°C on 3 September, 1977, and the lowest 4.7°C on 23 February, 1977 and 5.9°C on 5 March, 1978. Salinity also varied seasonally; generally it was higher than 33‰ and more constant in the fall and winter, and lower and more variable in other seasons.

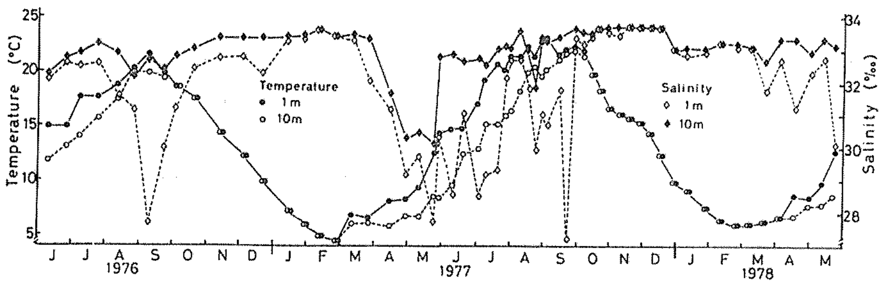

Fig. 2. Seasonal variation in water temperature and salinity at depths of 1 and 10 m at the sampling station.

Variation in Abundance of Zooplankton

Noctiluca miliaris (Fig. 3)

This large dinoflagellate occurred mainly in the warm period, being most abundant from July to October. The highest density was approximately 3 x 10^4 m^{-3} recorded on 10 August, 1976. No *N. miliaris* were found from November, 1976 to June, 1977. The population density was lower and the period of abundance was shorter in 1977 than the previous year, although a small number of organisms were present until midwinter.

Hydrozoa (Fig. 3)

Many species of medusae belonging to Hydroida and Siphonophora occurred in the plankton, but their species could not be identified. They were present almost the year round but particularly abundant from July to October in 1976. Like for *N. miliaris,* they were much fewer in 1977.

Chaetognatha (Fig. 3)

Since all the animals sampled could not be identified to species, the seasonal occurrence on a species basis was impossible to be demonstrated. However, *Sagitta crassa, S. crassa* f. *naikaiensis, S. enflata, S. minima* and *S. nagae* were most common. They appeared almost the year round, but their density was significantly higher in September and October of 1976.

Appendicularia (Fig. 3)

Oikopleura dioica was the dominant appendicularian in this bay, yet apparently several other species could also be observed. They were present throughout the year, but most abundant during the warm period from June to December.

Cladocera (Fig. 3)

Five cladoceran species identified as *Penilia avirostris, Evadone nordmanni, E. tergestina, Podon leuckarti* and *P. polyphemoides* appeared in Onagawa Bay, each of them displayed a remarkable seasonal occurrence. The period of appearance in the plankton was generally limited to several months of the year. In 1976, *P. avirostris* was taken only in August and September with the highest number of 1819 m^{-3}, while it was very scarce in the same months of 1977. *E. nordmanni* was present from June to August or September with an annual peak abundance of 1505 m^{-3} on 23 July, 1976 and 2161 m^{-3} on 8 July, 1977. In February and March of 1978, a very small number of this species appeared in the plankton. A congener, *E. tergestina,* increased in August and September with a maximum of 757 m^{-3} following the peak of *E. nordmanni.* The population density of this species was lesser in 1977. *P. leuckarti* appeared for a longer period than the other species, having 2 peaks in July and February or March, respectively. The highest population density was 2996 m^{-3} on 8 July, 1977. Another *Podon, P. polyphemoides,* was present from August to December when *P. leuckarti* was scarce in the plankton.

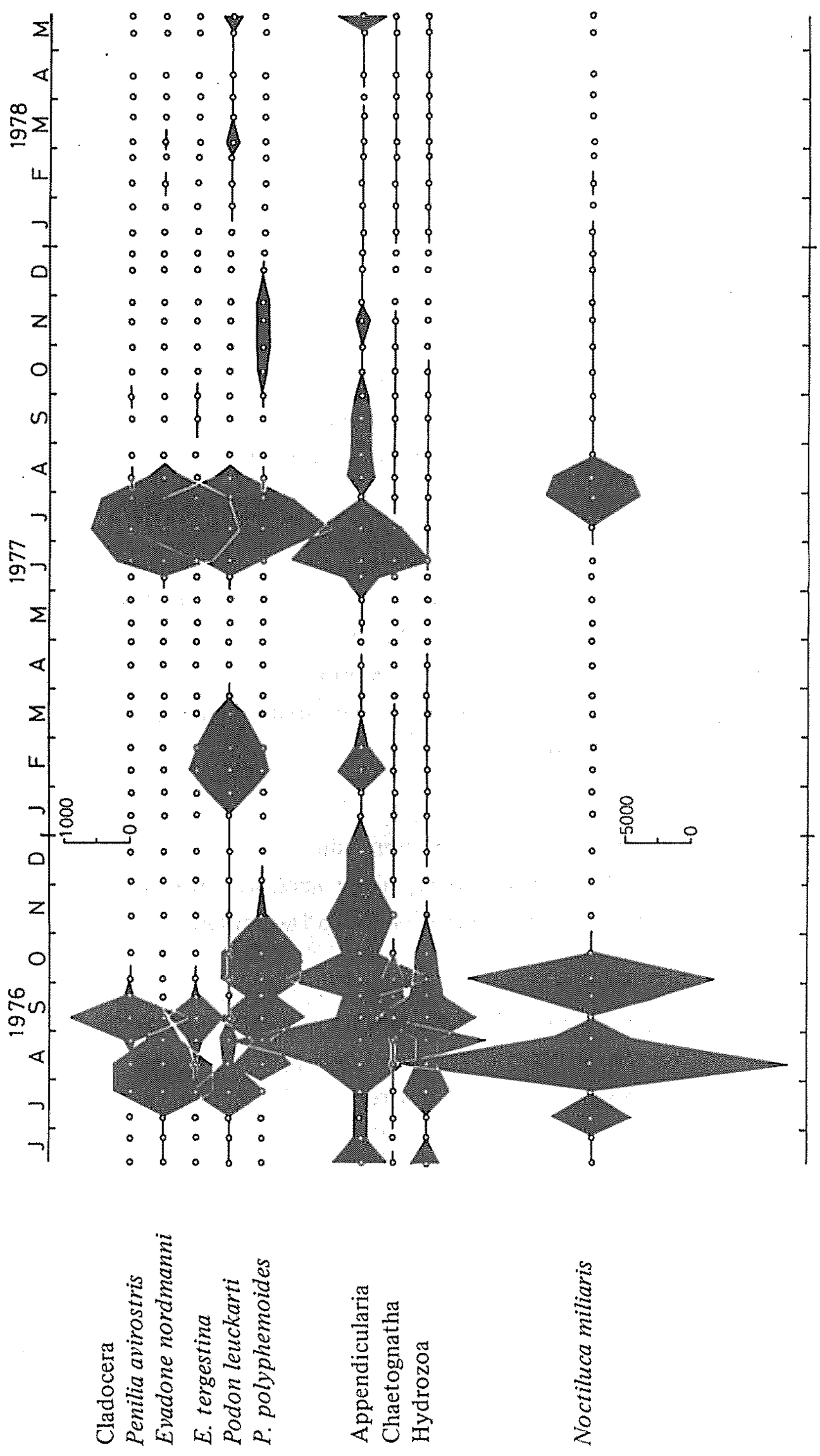

Fig. 3. Seasonal variation in abundance of Cladocera, Appendicularia, Chaetognatha, Hydrozoa and *Noctiluca miliaris*. *N. miliaris* has a different scale.

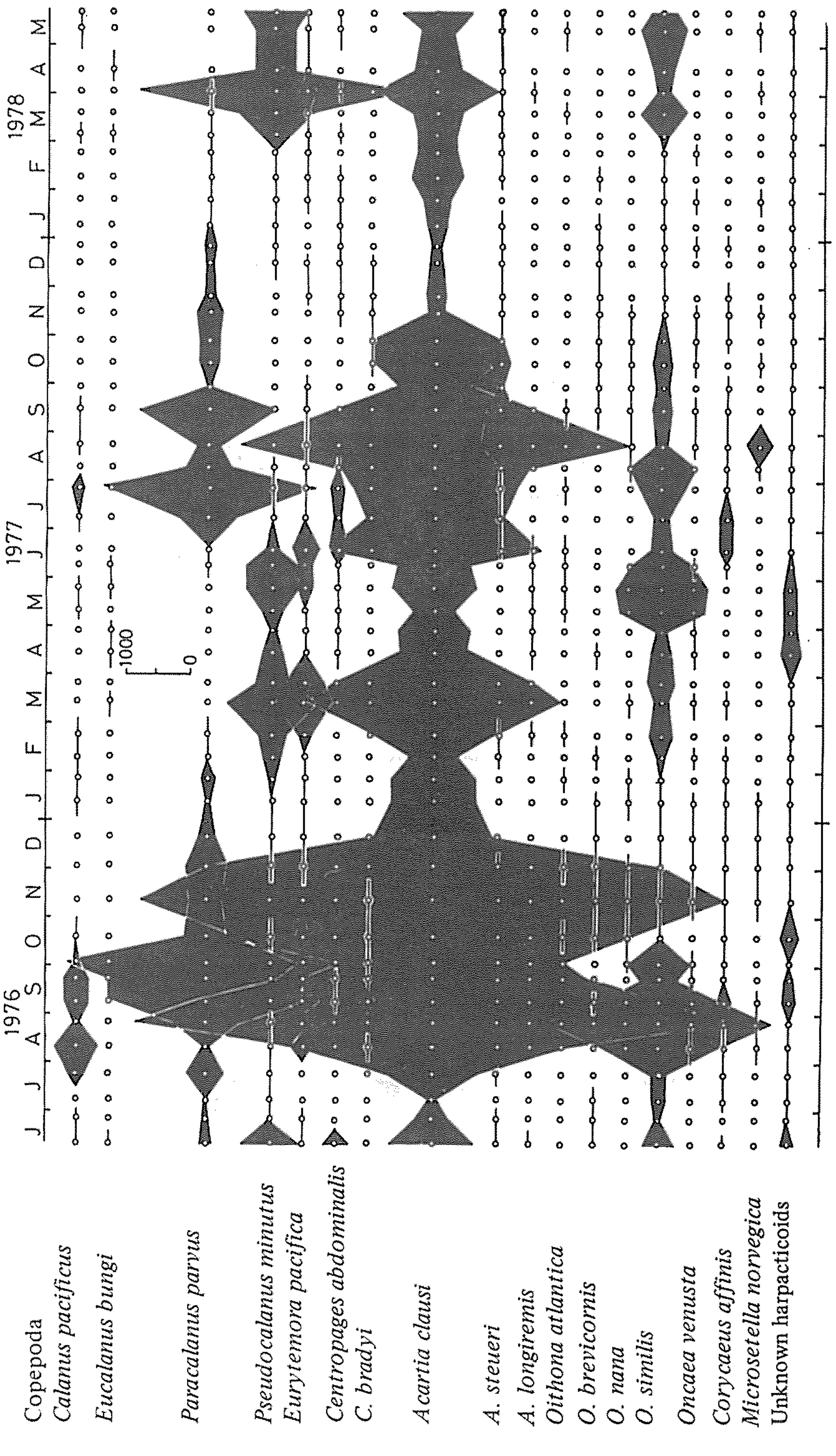

Fig. 4. Seasonal variation of abundance of Copepoda.

Copepoda (Fig. 4)

A total of 26 species of copepods with several unidentified harpacticoid copepods were collected during the present study. Among these, the seasonal variation in abundance of 17 common species is shown in Fig. 4 including the unidentified harpacticoids. The copepods which appeared throughout the year in the innermost part of Onagawa Bay were only *Acartia clausi* and *Oithona similis.* The other species more or less disappeared from the sampling site during some time of the year. *Calanus pacificus* occurred mainly in the summer and sporadically in small numbers in other seasons. *Eucalanus bungi* was found only in the spring when the water temperature was lowest. *Paracalanus parvus* was abundant in warm seasons, but no animals were found in the spring. On the contrary, *Pseudocalanus minutus* and *Eurytemora pacifica* were abundant in the spring, but were greatly reduced in the summer and fall. Two species of *Centropages, C. abdominalis* and *C. braydi,* appeared infrequently. *Acartia clausi* was the dominant species at the sampling site; it was abundant throughout the year while the highest population density was observed during summer and fall. *A. steueri* was also common in the warm seasons. However, *A. longiremis* was found in the cold seasons in very few numbers. Four species of the genus *Oithona* were common, among which *O. similis* was most abundant followed by *O. brevicornis. O. atlantica* and *O. nana* were infrequently observed. *Oncaea venusta* and *Corycaeus affinis* were commonly present almost throughout the year. *Microsetella norvegica,* a planktonic harpacticoid, appeared in small numbers at infrequent intervals throughout the year. Unknown species of harpacticoid were usually present in the plankton.

VARIATION IN COMPOSITION OF ABUNDANT COPEPODS (Fig. 5)

Paracalanus parvus, Pseudocalanus minutus, Eurytemora pacifica, Acartia clausi and *Oithona similis* were the dominant 5 species, usually exceeding over 90% of the total copepod abundance. *A. clausi* was the most abundant copepod accounting for more than

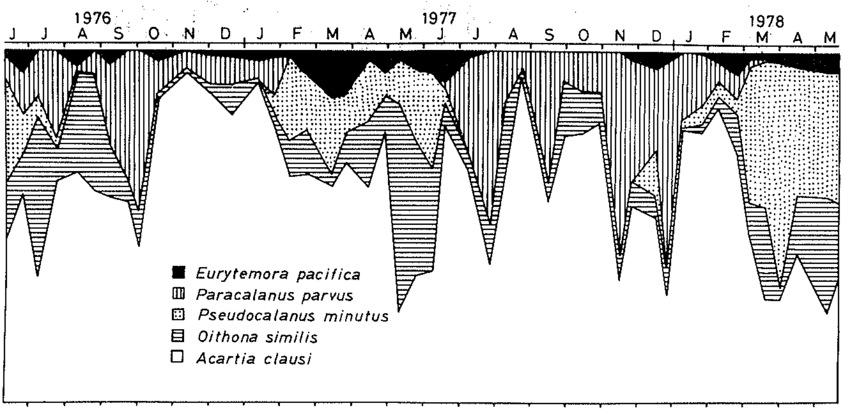

Fig. 5. Seasonal variation in composition of *Eurytemora pacifica, Paracalanus parvus, Pseudocalanus minutus, Oithona similis* and *Acartia clausi.*

50% during most of the year. It dominated from October, 1976 to January, 1977, although it was not equally abundnat for the same period of the following year, when the composition changed greatly at shorter intervals. A constant occupation of *O. similis* in the plankton accounted for 2-60% through the investigation. Its preponderence was remarkable in late spring to early summer. *E. pacifica* appeared rather sporadically but increased in the spring. *Pseudocalanus minutus* was also abundant in the spring like *E. pacifica,* and accounting for a maximum of 64% of the total copepod abundance. Disappearance of *Pseudocalanus minutus* coincided with the appearance of *Paracalanus parvus* which was the second most abundant copepod in the summer and fall following *A. clausi.*

DISCUSSION

Although the seasonal cycles of population abundance of zooplankton have been studied at many inlet waters along the Japanese coast, nothing was known about this at the inlets along the Rias coast of Sanriku District, except for a report on the zooplankton in Otsuchi Bay, approximately 100 km north of Onagawa Bay (TERASAKI, 1980)[2]. TERASAKI studied the seasonal changes in the composition of zooplankton at three different stations established in Otsuchi Bay. There are many similarities in species composition and seasonal cycles of dominant species between Onagawa Bay and Otsuchi Bay. However, more offshore organisms such as *Euphausia pacifica* (Euphausiacea), *Calanus plumchrus, Metridia* sp. (Copepoda) and *Sagitta elegans* (Chaetognatha) were found only in Otsuchi Bay. Topographical conditions of the inlet along this coast are characterized by deep indentation with the rugged steep of the shore, resembling a fjord. In such an environment, hydrographic conditions may be highly different horizontally from the mouth to the head of the inlet as well as vertically from the surface to the bottom. The seasonal distribution of zooplankton may consequently be affected by the change of the hydrographic conditions.

In temperate neritic waters, it is common phenomenon that many species of zooplankton vary in population density on a seasonal basis. In inlet waters along southern Japan, the range of annual temperature variation is often wider than 20°C, and in addition the variation is complete through the water column due to the shallow depth. In these areas, the seasonal prosperity and decay of the planktonic population is so clear for many species of copepods that the copepods can be divided into two groups, the summer-fall species and the winter-spring forms. In Onagawa Bay, however, such a clear seasonal segregation was not observed for many species of copepod, that were present in the plankton relatively constantly or sporadically irrespective of the season. This weak seasonality might be chiefly explained by the narrower temperature range of Onagawa Bay due to the presence of the cool water below the thermocline in the summer. Meanwhile, in spite of unclearness, *Calanus pacificus, Paracalanus parvus, Centropages bradyi, Acartia clausi, and Corycaeus affinis* were abundant mainly during summer-fall seasons, and *Pseudocalanus minutus* and *Eurytemora pacifica* were numerous during winter-spring seasons. *Oithona similis* did not belong to the above groups strictly; it was constantly plentiful from the spring to fall.

The lower water temperature in the summer of Onagawa Bay in comparison with that of inlets of southern Japan, may shift the period of population culmination. For instance, the appearance of *A. clausi* in the plankton is confined only to winter-spring seasons at coastal waters of southern Japan, i.e. December-June in Maizuru Bay (FURUHASHI, 1957)[3], January-June in Ise Bay (SEKIGUCHI, 1978)[4], December-July (HIROTA, 1964)[5], and November-July (KASAHARA *et al.*, 1975)[6] in the Inland Sea of Japan, March-June in Yatsusiro Kai (HIROTA and HARA, 1975)[7] and April and May in Kagoshima Bay (FUJII and SAISHO, 1973)[8], and then it is completely absent from the plankton owing to the higher summer temperature which is lethal to this species. *A. clausi* is no longer sustainable in planktonic form at temperatures far above 20°C. In Onagawa Bay, however, annual maximum temperature reaches above 20°C at the surface layer in the summer, while cooler water was present below the thermocline. So, *A. clausi* in this bay may be able to survive without any apparent thermal damage, and attains maximum density in the summer as a result of high population growth potential (UYE, 1981, 1982)[9,10]. This pattern is most typical in Akkeshi Bay, Hokkaido, where *A. clausi* is most abundant in the summer and greatly reduced in other seasons (KOYAMA, 1975)[11].

From the qualitative and quantitative surveys of the plankton in August of 1951, YAMAZI (1953)[1] found that the copepod communities in Onagawa Bay consisted of various components according to the distribution of the dominant species, i.e. *Acartia clausi-Oithona brevicornis* (referred to *O. nana* in his paper) community, *O. brevicornis* community, *O. brevicornis-A. clausi* community, *O. brevicornis-Oncaea* community, *O. brevicornis-Paracalanus parvus* community from the head to the mouth region of the bay. YAMAZI (1956)[12] later indicated that an inlet represented by such types of copepod communities reflects a great environmental variety from the inner to the outer region of the inlet. From the results of the present study, *A. clausi* appeared similarly as the dominant copepod at the innermost part of Onagawa Bay. *O. brevicornis*, however, did not cooccur abundantly with *A. clausi* to make a *A. clausi-O. brevicornis* community as YAMAZI has found. This may probably be due to undersampling of *O. brevicornis* since a large mesh opening (197 μm) was used in the present study. Onagawa Bay opens to the Pacific Ocean by a wide mouth, and this allows a high degree of water exchange between inner and outer portions of the bay, which in turn leads to a drastic change in the copepod community. However, the breakwaters may apparently inhibit the exchange of water between the harbor and the outer basin area. The present investigation was made only in the harbor area, and therefore the seasonal change in zooplankton community in the outer bay still remains to be studied. Neither *Calanus cristatus* and *C. plumchrus*, which are indicators for the cold Oyashio water, nor *Scolecithrix danae* and *Eucalanus mucronatus*, which are indicators for the warm Kuroshio water (ODATE, 1962)[13], were recorded at the sampling site, indicating that there is no direct inflow of offshore waters from the Oyashio or Kuroshio current into the innermost part of Onagawa Bay.

The total abundance of zooplankton in the first one year period was approximately 2 times higher than that of the second year. Particularly the difference in the population density of *A. clausi* was remarkable. Longer periods of more intensified investigations are needed to determine whether there are persistent trends in the abundance from year to year.

SUMMARY

The descriptions of the seasonal cycles in abundance of the major holozooplankton are made based on a 2 year period of net samples taken in the innermost part of Onagawa Bay, northeast mainland of Japan. *Acartia clausi* was the dominant copepod during most of the year, particularly abundant in the summer and fall, followed by *Paracalanus parvus*. *Eurytemora pacifica* and *Pseudocalanus minutus* were abundant in the winter and spring. *Oithona similis* was constantly present throughout the year, with peak abundance in the spring and summer. *Noctiluca miliaris*, Hydrozoa, Chaetognatha and Appendicularia were generally abundant in the summer and fall. Each of the 5 species of Cladocera displayed remarkable seasonal fluctuations in population abundance. The narrower range of annual temperature variation of Onagawa Bay allows relatively constant presence in the plankton for many species of organisms.

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女川湾奥部における主要動物プランクトンの季節変動

上　真　一

1976年6月から1978年5月までの2年間，宮城県女川湾の奥部で主要動物プランクトンの季節変動を調査した。

1. 合計26種の橈脚類（Copepoda）が同定され，そのうち *Acartia clausi* がほとんどの季節で最優占であった。特に本種は *Paracalanus parvus* とともに主として夏－秋期に多く出現した。*Eurytemora pacifica* と *Pseudocalanus minutus* は主として冬－春期に多く出現した。*Oithona similis* は春－夏期に多かった。多くの種はほとんど周年にわたって出現し，本邦南部の浅い内湾域で観察される様な顕著な季節的消長を示す種は少なかった。
2. 5種の枝角類（Cladocera）が出現し，各々の種は顕著な季節的消長を示した。
3. 鞭毛虫（Mastigophora）の一種のヤコウチュウ（*Noctiluca miliaris*），ヒドロ虫類（Hydrozoa），矢虫類（Chaetognatha）や尾虫類（Appendicularia）は主として夏－秋期に多く出現した。