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# Seasonal Variability in Abundance and Composition of Zooplankton in Toyama Bay, Southern Japan Sea*

Kazumasa HIRAKAWA,[1] Akira IMAMURA[2] and Tsutomu IKEDA[1]

## Abstract

Abundance and composition of zooplankton in Toyama Bay, the southern Japan Sea, was studied based on materials obtained from a series of vertical hauls (0-500m). The hauls were made using Norpac nets and were conducted at intervals of 2-4 weeks over one full year from February 1990 through January 1991. The annual maximum of total zooplankton biomass (wet weight) was found in late summer (August) despite the marked thermal stratification of the water column; and the total individual number peaked from April to early June, coinciding with the period from vertical mixing of the water column to early development of the thermocline. Euphausiids and amphipods, represented by *Euphausia pacifica* and *Themisto japonica*, respectively, played a major role in determining the seasonal pattern of zooplankton biomass for 0-500m depth. On the other hand, copepods were numerically the most important group. Furthermore, they were considered to be the most significant secondary producers in transporting primary production to higher trophic levels because of their close association with the spring phytoplankton bloom. While cold water species were predominant both in number and in biomass throughout the year, it was suggested that warm water species are important for supporting the growth of fish larvae in the surface layer during the summer and autumn, when the distribution of cold water species is limited below 100m depth.

**Key words** seasonal pattern, zooplankton, biomass, *Euphausia pacifica, Themisto japonica*, Copepoda, Toyama Bay

## Introduction

It is well known that boreal and subtropical faunas exist together in the greater part of the Japan Sea (NISHIMURA 1965a). In particular, the zoogeogaphical characteristics of the southern Japan Sea create an extensive admixture zone for these animals. However,

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1) Japan Sea National Fisheries Research Institute, Suido-cho, Niigata 951, Japan.
(〒951　新潟市水道町1丁目5939-22　日本海区水産研究所)
2) Toyama Prefectural Fisheries Experimental Station, Takatsuka, Namerikawa, Toyama 936, Japan.
(〒936　富山県滑川市高塚364　富山県水産試験場)

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little is known about the relationship between seasonal changes in the physical structure of the water column and the succession of zooplankton communities in this area.

AWAMORI (1984) regarded Toyama Bay as a semi-enclosed region, which is only seasonally affected by offshore waters. His judgement was based on the temporal succession of the copepod community, composed mainly of the oceanic warm water species *Oithona plumifera* and serveral neritic forms. HIRAKAWA *et al.* (1990) reported that the vertical separation of warm water copepods from cold water copepods was closely related to the well-developed two-layer hydrographical system, produced by the inflow of the warm Tsushima Current. Furthermore, HIRAKAWA (1991) pointed out that summer decreases in zooplankton population were offset by surface-dwelling southern warm water copepods, which advect into the region with the warm current. Consequently, it has been suggested that the spatial and temporal variabilities of the zooplankton community are more complicated with respect to the movements of coastal, warm water masses and deep cold water masses in Toyama Bay. However, until now there has been no year-round quantitative study of zooplankton communities incorporating all organisms from the surface through the mesopelagic layer. It has been noted that the conventional sampling methods employed in previous studies are characterized by extended sampling intervals (1-3 months) and shallower tow depths (primarily 0-150m). Therefore, the samples were inadequate for analyzing the population dynamics of either the warm water species, which have shorter generation times, or the cold water species, which perform extensive diel or

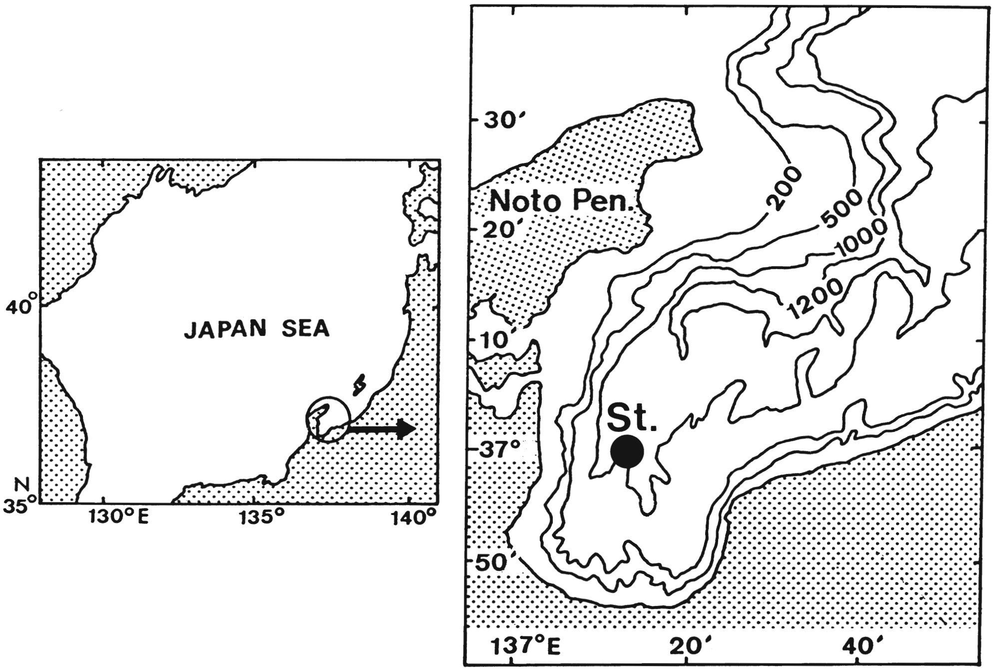

**Fig. 1.** Maps showing location of Toyama Bay (left), and position of the present sampling station in the central part of Toyama Bay (right). Bathymetric contours (1200, 1000, 500 and 200m) in Toyama Bay are also shown.

seasonal vertical migrations.

The purpose of this study is to describe seasonal variations of the numerical abundance, biomass, and composition of zooplankton in Toyama Bay over one full year. The interrelationships between abundance and hydrographical conditions are discussed ; and the reproductive cycles of some zooplankton groups as well as interaction with predators on zooplankton are discussed.

## Materials and Methods

Samplings were made aboard the R/V "Tateyama-Maru" of the Toyama Prefectural Fisheries Experimental Station at the station in the central part of Toyama Bay (37° 00' N, 137° 14' E, Fig. 1) from February 1990 through January 1991. Zooplankton was collected at intervals of approximately 2-4 weeks using a twin-type Norpac nets (45 cm mouth diameter, 0.33 mm and 0.10 mm mesh apertures). Each net was equipped with a Rigosha flow-meter on the mouth ring to register the water volume passing through the net. The nets were vertically towed from 500m depth to the surface, mostly during daylight hours (04:00-15:00). After collection, samples were preserved in a 10% buffered formalin-seawater solution. Microplankton samples obtained with the 0.10 mm mesh net were treated as described below, and those obtained with the 0.35 mm mesh net were used for analyzing the abundance and composition of the zooplankton. At each sampling, the temperature and salinity profiles between 0-500m depth were recorded using a CTD system (Neil Brown).

In the land laboratory, large specimens such as gelatinous animals and fish larvae were first removed from the zooplankton samples. The samples were then sorted under a dissecting microscope into each taxonomic group of animals. Siphonophores were found to be broken and were thus omitted from the results because of the difficulty in quantitaively assessing their abundance. Samples were then split into 1/2 or 1/4 aliquots using a Folsom plankton splitter for sorting smaller zooplankton. After sorting, each taxonomic group was weighed (wet weight) on a top-pan balance, accurate to 0.01mg. Species analyses were made primarily for copepods, the most dominant group as reported by HIRAKAWA *at al.* (1990).

The settling volume of samples collected with the 0.10 mm mesh net was measured as an index of the microplankton (a mixture of zooplankton and phytoplankton) abundance. At each sampling, the entire catch was filtered through 2.0 mm mesh nettings and poured into a 100 m*l* measuring cylinder, graduated to 1.0 m*l*. After being left undisturbed for 24 h, the settled volume of the samples was recorded. The settled volume of this 0.1-2.0 mm fraction was converted to wet weight by multiplying by 0.26 (MORIOKA)*

## Results

### 1 Temperature and salinity structures of 0-500m water column

Vertical profiles of the temperature and salinity in the upper 500m depth between February 1990 and January 1991 are shown in Fig. 2. The surface temperature varied from

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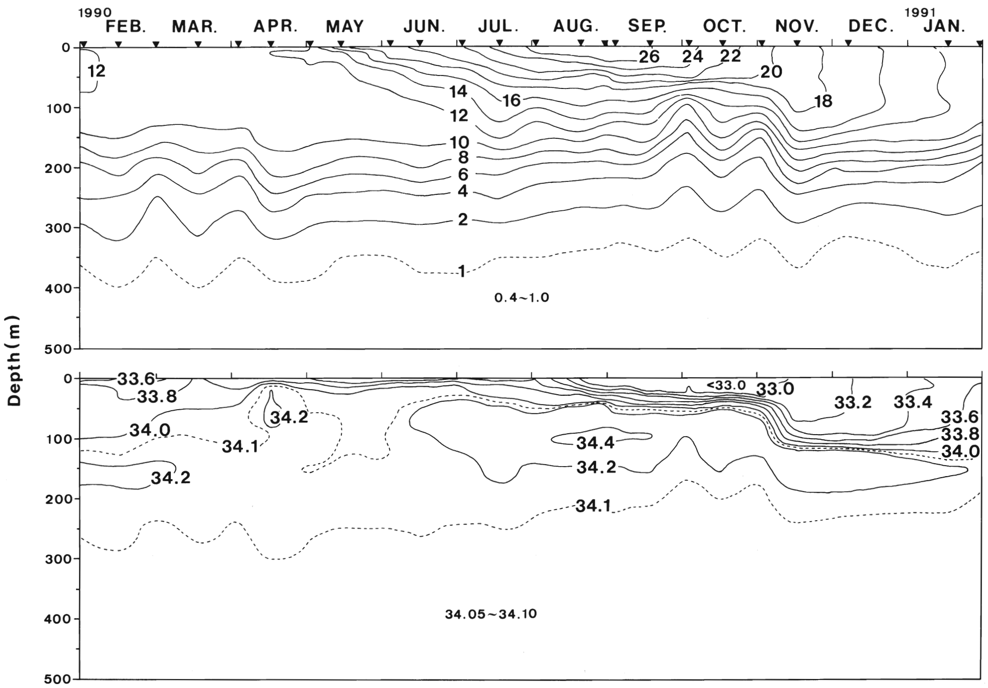

**Fig. 2.** Seasonal changes in temperature (upper, ℃) and salinity (lower, ‰) in the upper 500m depth at the station in the central part of Toyama Bay during the period fron February 1990 to January 1991. Solid triangle denotes date of observations.

a minimum of 10.5℃ in March to a maximum of 27.9℃ in August. The surface water in the upper 150m depth was thermally homogeneous (10-12℃) from February to mid-April. Surface warming occurred from April to mid-September. During warming, a weak seasonal thermocline formed in mid-late April and sharpened from August through mid-September, when the temperature of the upper mixed layer reached 26℃. Below this seasonal thermocline, a permanent thermocline exists around 150-300m depth where the temperature decreased from 10℃ to 2℃. Surface cooling and subsequent vertical mixing broke the seasonal thermocline during the period from late September to late October, and a single permanent thermocline persisted from late November through early April. The temperature of the water bellow 350m depth was consistently lower than 1.0℃ throughout the year.

Salinity in the upper 150m depth also changed seasonally. Low salinity water (<33.0 ‰) was observed in the upper 20m depth from late August to early November. The maximum salinity over 34.4 ‰ was found at 75-100m depth during August and September. This is considered to be linked to the warm Tsushima Current, which is characterized by high salinity (34.2-34.7 ‰) (SHUTO 1982). This warm current was first observed at 50m depth in June. It appeared to remain until early March of the next year at a deeper depth of around 150m, forming a maximum salinity layer. Salinity below 300m depth was nearly homogeneous (34.05-34.10 ‰) and remained unchanged throughout the year.

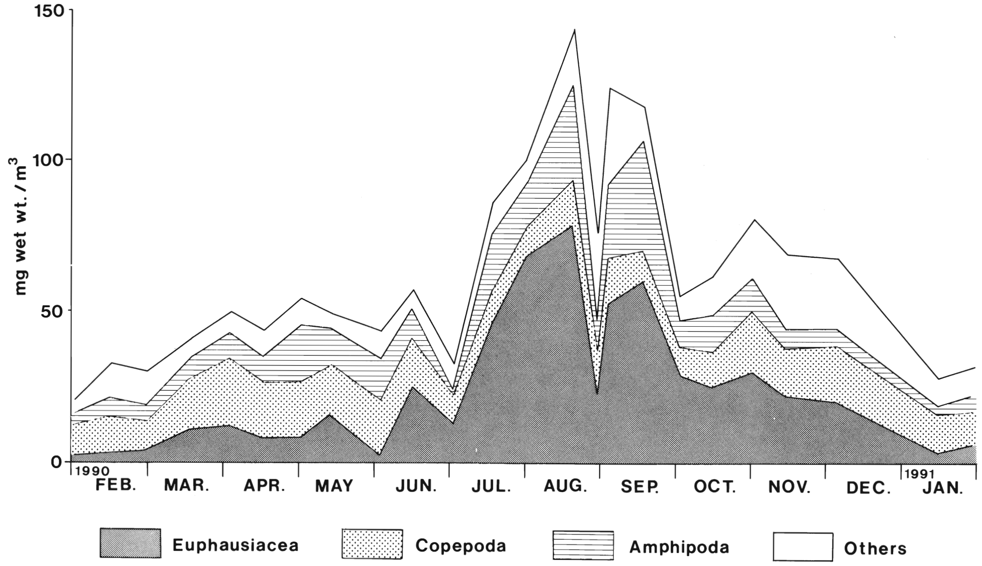

**Fig. 3.** Seasonal variation in the total biomass in wet weight (mg/m³) and composition of zooplankton community at the station in the central part of Toyama Bay during the period from February 1990 to January 1991.

## 2 Biomass and composition of zooplankton

The data for zooplankton biomass in wet weight are summarized in Appendix 1 and illustrated in Fig. 3. The total biomass increased gradually from a winter minimum (20.6 mg/m³) in February to a small spring/early summer peak (54.5-57.3 mg/m³) in April-June. The biomass attained a annual maximum (143.8 mg/m³) in August. It decreased to 55.5 mg/m³ in early October and then recovered to 80.9 mg/m³, attaining a small autumn peak in early November. The biomass again decreased to a winter minimum in January.

**Table 1.** Annual mean percentages (ranges) in the biomass in wet weight and in individual number of the eight major zooplankton groups at the station in the central part of Toyama Bay during the period from February 1990 to January 1991.

| Zooplankton group | Biomass (mg wet weight/m³) | Number (Individual/m³) |
|---|---|---|
| Copepoda | 28.4 ( 8.6−49.6) | 63.2 (41.7−86.3) |
| Amphipoda | 17.9 ( 3.2−34.3) | 2.5 ( 0.4−11.1) |
| Euphausiacea | 31.3 ( 4.7−68.1) | 5.9 ( 0.7−27.5) |
| Cladocera | 0.3 ( 0.0− 2.8) | 2.4 ( 0.0−30.5) |
| Ostracoda | 4.6 ( 1.6− 7.9) | 12.3 ( 4.4−31.1) |
| Chaetognatha | 11.4 ( 2.1−26.6) | 4.6 ( 0.2−13.7) |
| Appendicularia | 0.4 ( 0.0− 1.2) | 3.4 ( 0.6−10.0) |
| Others | 5.7 ( 0.5−21.7) | 5.7 ( 0.5−24.4) |

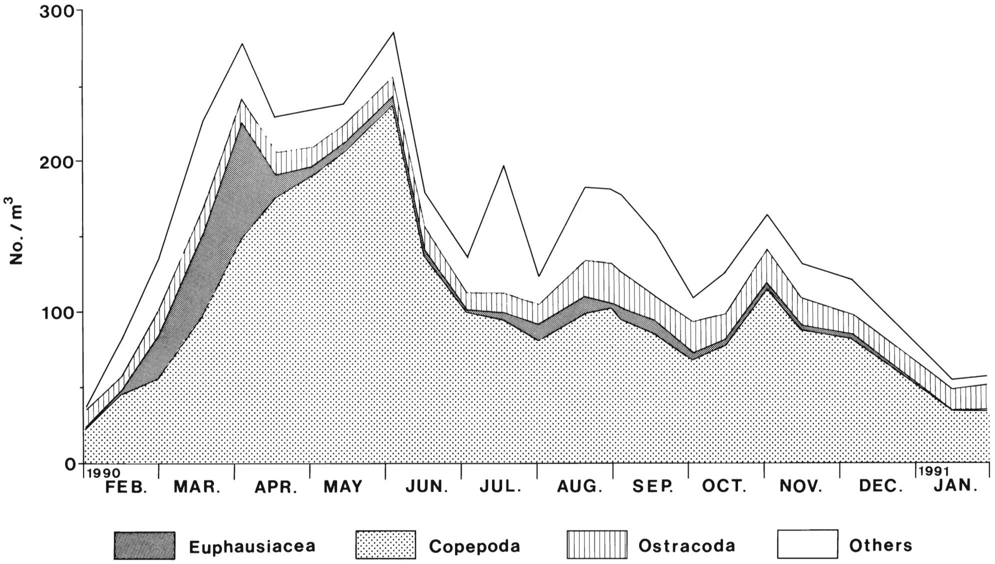

**Fig. 4.** Seasonal variation in the total number (individual/m$^3$) and composition of zooplankton community at the station in the central part of Toyama Bay during the period from February 1990 to January 1991.

Various taxa including Copepoda,Ostracoda,Euphausiacea,Amphipoda,Chaetognatha, Cladocera, Mysidacea, Appendicularia, Polychaeta, benthic invertebrates such as barnacle and echinoderm larvae, fish eggs and larvae, and others were observed. The percentage contribution, based on weight, of each taxon was calculated for each sample and is given in Appendix 1. According to the mean percentages for the year, Euphausiacea, Copepoda, and Amphipoda were the three major zooplankton groups, comprising 31.3, 28.4 and 17.9% of the total biomass, respectively (Table 1). The seasonal fluctuation of the euphausiid biomass, with its annual maximum (78.3 mg/m$^3$) in mid-August, was determinative in that of the total zooplankton biomass. Apparently, Euphausiacea (mainly *Euphausia pacifica*) was the most important factor in the variation of the zooplankton biomass throughout the year. Copepoda was the second most important taxon, comprising 32.5-49.6% of the total biomass from February to early June (Appendix 1). Amphipoda (mainly *Themisto japonica*) was dominant in August and September, and was the tertiary contributor to the total biomass. Among the other zooplankton groups, Chaetognatha was responsible for a small autumn increase in the total zooplankton biomass (Appendix 1).

### 3 Individual number and composition of zooplankton

The data for individual number of the same samples are summarized in Appendix 2 and illustrated in Fig. 4. The seasonal variation in the total zooplankton number exhibited a different pattern from that of the total zooplankton biomass. The total number increased rapidly from a winter minimum in February to early April. This higher number continued until early June, reaching a broad annual maximum (277-285 ind/m$^3$). The zooplankton number then decreased rather irregularly towards a winter minimum in January (37 ind/

**Table 2.** Dominant copepod species[a] at the station in the central part of Toyama Bay during the period from February 1 to June 3 in 1990.

| Warm water species | Cold water species |
|---|---|
| *Mesocalanus tenuicornis* | *Pseudocalanus minutus* |
| *Paracalanus* sp. | *Pareuchaeta japonica* |
| *Ctenocalanus vanus* | *Scolecithricella dentata* |
| | *Scolecithricella minor* |
| | *Metridia pacifica* |
| | *Oithona atlantica* |

[a] determined for each sample by the definition of HOSOKAWA *et al.*(1968) as follows,

$$\text{Dominant species: } N_i > (1/S) \sum_{i=1}^{S} N_i$$

where N*i* is number of the *i*-th species and S is the total number of species.

m³), showing small peaks in July, August, and early November.

Copepoda was the most important component, constituting approximately 40-90% of the total zooplankton number throughout the year (annual mean; 63.2%) (Table 1). A sharp increase in the number of Copepoda was found during the period from early February (annual minimum; 22 ind/m³) to early June (annual maximum; 237 ind/m³). Therefore, Copepoda was primarily responsible for seasonal variations in the total zooplankton number. A total of 33 copepod species were identified during the period from February to early June (Appendix 3). Among these copepods, three cold water species and six warm water species were dominant (Table 2). In particular, cold water *Metridia pacifica* and *Oithona atlantica* were predominant over the entire period (Appendix 3); the former having a maximum (4773 ind/100 m³) in early April and latter having a maximum (19319 ind/100 m³) in early June.

Ostracoda, represented exclusively by a mesopelagic species *Conchoecia pseudodiscophora*, was the next most abundant group. This occurred year-round with an annual mean of 12.3% of the total zooplankton number (Table 1). There was no definable seasonal trend; the numbers ranged 11 to 26 ind/m³. Although the number of Euphausiacea increased from late February to April, along with Copepoda, it ranked behind Ostracoda on the basis of annual mean (5.9% of the total zooplankton number) (Table 1). Dominancies of the other groups, based on annual mean, were as follows: Chaetognatha (4.6%), Appendicularia (3.4%), Amphipoda (2.5%) and Cladocera (2.4%) (Table 1).

## Discussion

MORIOKA (1985) studied zooplankton biomass in the southern Japan Sea, including Toyama Bay, over a long-term period (from 1965 to 1985). The zooplankton was obtained mainly with Norpac net (0.33 mm mesh apertures) from the upper 150m depth. He observed that the biomass reached an annual maximum (mean ca. 100 mg wet weight/m³) in April, just after the completion of winter convection. In contrast, the maximum zooplankton biomass in the upper 500m depth of Toyama Bay was found during late August in this study, despite strong development of the thermal stratification of the water column.

These contradictory results regarding the timing of the annual zooplankton biomass maxima may be explained by the difference in sampling methods employed by MORIOKA (1985) and this study. In this study, both *Euphausia pacifica* and *Themisto japonica* were found to be the major contributors to the total zooplankton biomass in Toyama Bay during the summer season. According to KOMAKI (1974) and IGUCHI*, *E. pacifica* spawns in early spring, and the resulting offspring grow actively from spring to summer. *E. pacifica* is known as an extensive diel vertical migrant and a primarily cold-adapted species. Its vertical distribution range is limited below 150m depth in summer because they prefer cold water to the higher temperature of the shallow layers (ODATE 1991). For a similar reason, a major part of the *T. japonica* population is also confined within the bathymetric level, below 200m depth, in Toyama Bay during the summer (IKEDA *et al.* 1992). Therefore, it

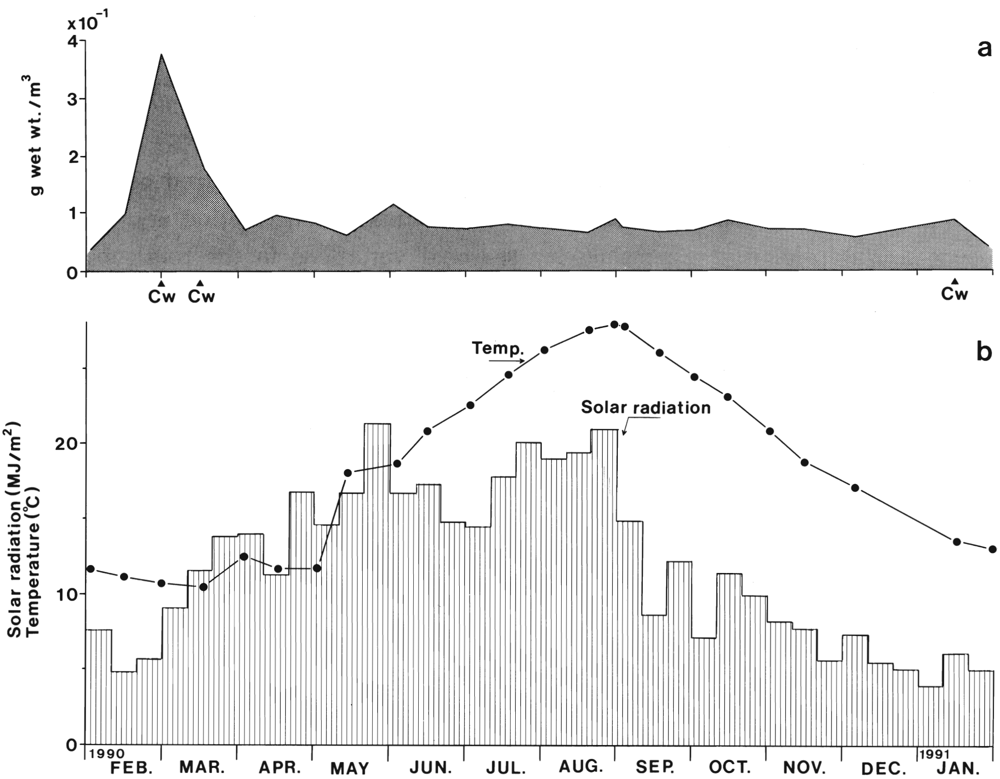

**Fig. 5.** Seasonal variations in microplankton (0.1–2.0 mm fraction) biomass (g wet weight/m$^3$) (a), surface water temperature (℃) and solar radiation (MJ/m$^2$) (b) at the station in the central part of Toyama Bay during the period from February 1990 to January 1991. Cw denotes the sampling date when *Coscinodiscus wailesii* predominated.

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is clear that neither *E. pacifica* nor *T. japonica* was collected abundantly in the shallow net hauls by MORIOKA (1985).

The development of the thermal stratification of the water column by surface warming in the summer may have a significant impact on the life cycles of primarily cold-adapted zooplankton populations. The upper limit for the maximum layer of cold water zooplankton populations could be described by a 10-12℃ isotherm in the southern Japan Sea (MORIOKA and KOMAKI 1978). According to HIRAKAWA (1991), *Metridia pacifica*, a dominant cold water copepod in Toyama Bay, migrates daily between the surface and 300m depth in early June. However, the depth range of diel migration and the reproductive capability of this species is significantly reduced during late summer. HIRAKAWA (1991) described that reproduction and vertical migration were confined by the higher temperature (>18℃) during the summer. A remarkable descent in depth of population maxima of cold water copepods during the summer may be a characteristic feature commonly seen in the southern Japan Sea. The surface water temperature has been considered a major factor which limits the vertical range of their diel migrations (HANSEN 1951; VINOGRADOV 1968; MCLAREN 1969; MARLOW and MILLER 1975).

In order to put the production cycle in Toyama Bay in a wider perspective, data for microplankton biomass, surface water temperature, and solar radiation (Fig. 5) were

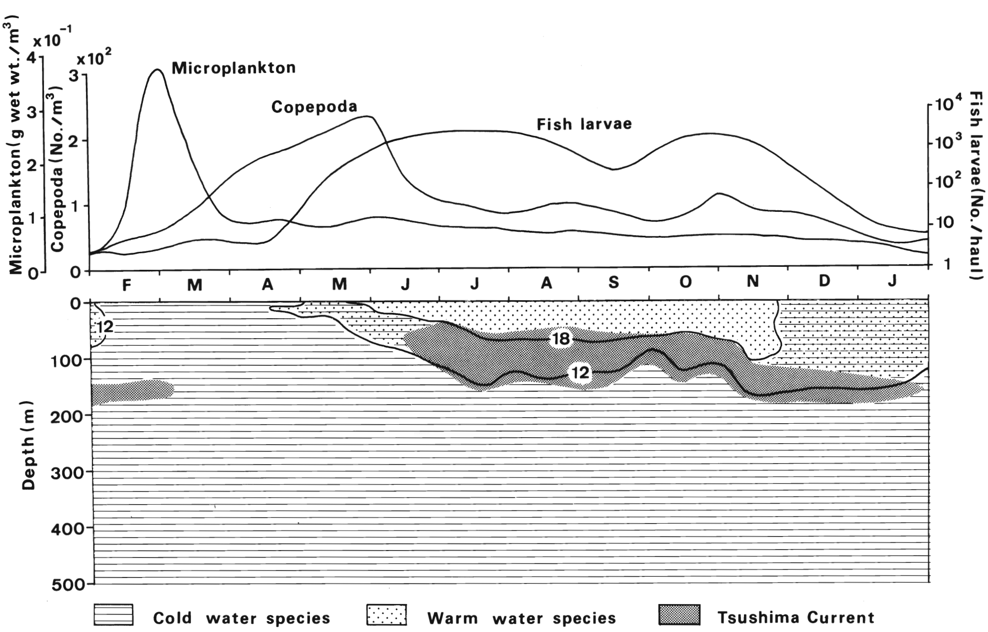

**Fig. 6.** Schematic diagrams showing the seasonal cycles in abundance of microplankton, copepods and fish larvae (upper) and in vertical separation of copepod populations affected by thermal stratification of water column and inflow of the warm Tsushima Current (lower) in Toyama Bay. Data of fish larvae are adapted from HAYASHI (1990). Isotherms of 12℃ and 18℃ are selected based on MORIOKA and KOMAKI (1978) and HIRAKAWA (1991), respectively (see text).

compared with those of zooplankton number (Fig. 4). The peak in microplankton biomass during February-March was attained exclusively by a large-sized subtropical centric diatom, *Coscinodiscus wailesii* (Fig. 5a). *C. wailesii* is well known as an appropriate indicator species of the spring phytoplankton bloom in the central and southeastern Japan Sea (NISHIMURA 1965b). The current results suggest that rapid growth of this diatom occurred under lower surface temperatures (10.5-13.6℃) and increasing solar radiation (4.0 to 11.5 MJ/$m^2$) in Toyama Bay from winter to early spring (Fig. 5b). Clearly, the spring bloom of the diatom coincides with the mixing of the water column and the gradual increase in solar radiation intensity in this region. The number of Copepoda as a whole increased following the annual maximum of microplankton biomass. Thus, the spring bloom of the diatom appears to be exploited inefficiently by both the cold and warm water copepod communities of Toyama Bay (Fig. 6). This may agree with the "unbalanced" production cycle being proposed by HEINRICH (1962) and NISHIMURA (1969) for the ecosystem of the central and southeastern (offshore water) Japan Sea, where large grazing copepods, *Calanus cristatus* and *C. plumchrus*, grow into late copepodids after the spring bloom of phytoplankton.

MATANO (1984) reported that the Copepoda were major prey organisms of commercial fishes in Toyama Bay. Fish reproduction and the resulting larvae are most abundant in the summer and autumn in Toyama Bay (HAYASHI 1990). In light of the general zooplankton cycles of this region (Fig. 6), dominant cold water copepods such as *Pseudocalanus minutus, Scolecithricella minor*, and *Metridia pacifica* are unlikely to become important prey organisms of the fish larvae such as *Engraulis japonicus* and *Maurolicus muelleri*, which are distributed in the upper 150m depth in the summer. Instead, warm water copepods inhabiting in the upper layer such as *Calanus sinicus, Undinula vulgaris, Acrocalanus gracilis, Clausocalanus arcuicornis,* and *Oncaea venusta* can become major prey organisms. They are brought in with the warm Tsushima Current and reproduce in the upper 100m depth (HIRAKAWA 1991) (Fig. 6). In fact, *O. venusta* was most abundantly found in fecal pellets (ISEKI and HIRAKAWA 1990) of *E. japonicus* larvae and in the stomach contents (MATANO 1984) of its immatures during the summer. Therefore, these oceanic warm water species would be an alternative food source for icthyoplankton growth during the warmest and thermally stratified periods in Toyama Bay.

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## References

AWAMORI, S. (1984) (Zooplankton distribution in Toyama Bay). *The Study on Potential Productivity of Marine Organisms and Oceanographic Environment*, Japan Sea Natl. Fish.

Res. Inst., 205-216. (In Japanese)

HANSEN, K. V. (1951) On the diurnal migration of zooplankton in relation to the discontinuty layer. *J. Cons. perm. int. Explor. Mer.*, **17** (3), 231-241.

HAYASHI, S. (1990) Seasonal abundance and vertical distribution of fish eggs and larvae in Toyama Bay, the Japan Sea. *Bull. Toyama Pre. Fish. Exp. Stn.*, (2), 1-17. (In Japanese with English abstract)

HEINRICH, A. K. (1962) The life histories of plankton animals and seasonal cycles of plankton communities in the oceans. *J. Cons. perm. int. Explor. Mer.*, **27**, 15-24.

HIRAKAWA, K. (1991) Vertical distribution and reproduction of planktonic copepods in Toyama Bay, southern Japan Sea, with special reference to *Metridia pacifica*. *Bull. Plankton Soc. Japan*, spec. Vol., 373-382.

HIRAKAWA, K., IKEDA, T. and KAJIHARA, N. (1990) Vertical distribution of zooplankton in Toyama Bay, southern Japan Sea, with special reference to Copepoda. *Bull. Plankton Soc. Japan*, **37** (2), 111-126.

HOSOKAWA, T., KATO, M., KITAZAWA, Y., NOMURA, K., TAGUCHI, R., TORII, Y. and YAGI, S. (1968) (An Introduction to Ecology). Yokendo, Tokyo, 154-155. (In Japanese)

IKEDA, T., HIRAKAWA, K. and IMAMURA, A. (1992) Abundance, population structure and life cycle of a hyperiid amphipod, *Themisto japonica* (BOVALLIUS), in Toyama Bay, southern Japan Sea. *Bull. Plankton Soc. Japan*, **39** (1), (In press).

ISEKI, K. and HIRAKAWA, K. (1990) Sinking particulate matters in Toyama Bay during summer, with special reference to large fecal pellets. Abstract presented to the autumn conference of Oceanographical Society of Japan, 1990, 317 (In Japanese)

KOMAKI, Y. (1974) Euphausiids, especially *Euphausia pacifica* H. J. HANSEN in the Japanese waters. *JAMARC*, (5), 2-9. (In Japanese)

MARLOWE, C. J. and MILLER, C. B. (1975) Patterns of vertical distribution and migration of zooplankton at Ocean Station "P". *Limnol. Oceanogr.*, **20** (5), 824-844.

MATANO, Y. (1984) (Ecosystem characteristics of Toyama Bay as viewed from fishes). *The Study on Potential Productivity of Marine Organisms and Oceanographic Environment*, Japan Sea Natl. Fish. Res. Inst., 233-252. (In Japanese)

MCLAREN, I. A. (1969) Population and production ecology of zooplankton in Ogac Lake, a landlocked fiord on Baffin Island. *J. Fish. Res. Bd. Canada*, **26** (6), 1485-1559.

MORIOKA, Y. (1985) Zooplankton distribution in the Japan Sea. *Bull. Japan Soc. Fish. Oceanogr.*, (47/48), 63-66. (In Japanese)

MORIOKA, Y. and KOMAKI, Y. (1978) Seasonal and vertical distribution of zooplankton biomass in the Japan Sea. *Bull. Japan Sea Reg. Fish. Lab.*, (29), 255-267. (In Japanese with English abstract)

NISHIMURA, S. (1965a) The zoogeographical aspects of the Japan Sea Part I. *Publ. Seto Mar. Biol. Lab.*, **13** (1), 35-79.

NISHIMURA, S. (1965b) The zoogeographical aspects of the Japan Sea Part II. *Publ. Seto Mar. Biol. Lab.*, **13** (2), 81-101.

NISHIMURA, S. (1969) The zoogeographical aspects of the Japan Sea Part V. *Publ. Seto Mar. Biol. Lab.*, **17** (2), 67-142.

ODATE, K. (1991) Fishery biology of the krill, *Euphausia pacifica*, in the northeastern coast of Japan. *Suisan-Kenkyu-Sosho*, **40**, 1-97. (In Japanese)

SHUTO, K. (1982) A review of sea conditions in the Japan Sea (II). *Umi to Sora*, 57 (4), 171-186. (In Japanese with English abstract)

VINOGRADOV, M. E. (1968) *Vertical Distribution of the Oceanic Zooplankton*. Akad. Nauk SSSR Inst. Okeanol., Moscow (English translation, I.P.S.T., Jerusalem 1970). 93-114.

# 日本海南部の富山湾における動物プランクトンの出現量及び組成の季節変化

平川和正・今村 明・池田 勉

富山湾における動物プランクトンの出現量（現存量・個体数）及び組成の季節変化のパターンを明かにするため，1990年2月～1991年1月迄の期間中約2～4週間毎に一連のノルパックネット鉛直曳（0～500m深）採集を実施した．動物プランクトン総個体数は，水塊の鉛直混合末期に当る4月から水温躍層発達初期の6月初めにかけて年間最大に達した．これに対し，動物プランクトン総現存量（湿重量）の最大は，昇温による更に顕著な水塊の成層化にも拘らず8月下旬に観察された．

オキアミ類及び端脚類（各々優占種 *Euphausia pacifica* 及び *Themisto japonica*）は表層から500m深までの動物プランクトン現存量の季節パターンを決定する主要群となった．他方，個体数で最優占群となったかいあし類の季節変化は植物プランクトン春季増殖と密接な関連を示したことから，本群は基礎生産を高次消費者へ転送する二次生産者として最も重要な役割を果たしているものとみなした．冷水性動物プランクトンは個体数及び現存量共に年間を通じ卓越した．しかしながら，それらの生息分布深度が100m以深に制限される夏・秋季の高水温期には，替って暖水性種が稚仔魚・未成魚の成長を支えるうえで重要な位置を占めると言えよう．

**Appendix 1**. Wet weight (mg/haul) of the eight major zooplankton groups at the station in the central part of Toyama Bay during the period from February 1990 to January 1991. Numbers in parentheses denote their relative abundance in percentages to the total.

| | 1990 | | | | | | | | | | | | | | | | | | | | | | 1991 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling date | Feb. | | | Mar. | Apr. | | May. | | Jun. | | Jul. | | Aug. | | | Sep. | | Oct. | | Nov. | | Dec. | Jan. | |
| | 1 | 14 | 28 | 17 | 3 | 16 | 1 | 14 | 3 | 15 | 2 | 17 | 1 | 20 | 30 | 3 | 17 | 2 | 15 | 1 | 15 | 5 | 16 | 30 |
| Vol. of sea water filtered (m$^3$) | 82.9 | 88.1 | 77.4 | 81.9 | 69.9 | 75.5 | 81.7 | 79.4 | 83.4 | 78.4 | 79.0 | 86.0 | 79.8 | 79.6 | 81.7 | 88.1 | 80.0 | 75.3 | 78.2 | 80.2 | 80.0 | 84.8 | 82.6 | 80.1 |
| Total wet wt. | 1708 | 2902 | 2314 | 3371 | 3477 | 3309 | 4452 | 3923 | 3639 | 4493 | 2593 | 7389 | 7988 | 11448 | 6213 | 10940 | 9464 | 4179 | 4833 | 6485 | 5522 | 5750 | 2358 | 2591 |
| Copepoda | 847 | 1088 | 752 | 1396 | 1583 | 1396 | 1497 | 1350 | 1530 | 1232 | 763 | 957 | 838 | 1207 | 1199 | 1347 | 809 | 759 | 920 | 1644 | 1314 | 1614 | 1032 | 855 |
| | (49.6) | (37.5) | (32.5) | (41.4) | (45.5) | (42.2) | (33.6) | (34.4) | (42.0) | (27.4) | (29.4) | (13.0) | (10.5) | (10.5) | (19.3) | (12.3) | (8.6) | (18.2) | (19.0) | (25.4) | (23.8) | (28.1) | (43.8) | (33.0) |
| Amphipoda | 289 | 549 | 440 | 553 | 576 | 608 | 1529 | 970 | 1126 | 738 | 83 | 1611 | 1086 | 2535 | 870 | 2155 | 2963 | 648 | 952 | 867 | 515 | 446 | 240 | 416 |
| | (16.9) | (18.9) | (19.0) | (16.4) | (16.6) | (18.4) | (34.3) | (24.7) | (30.9) | (16.4) | (3.2) | (21.8) | (13.6) | (22.1) | (14.0) | (19.7) | (31.3) | (15.5) | (19.7) | (13.4) | (9.3) | (7.8) | (10.2) | (16.1) |
| Euphausiacea | 176 | 238 | 289 | 864 | 832 | 600 | 669 | 1215 | 171 | 1987 | 1007 | 3910 | 5442 | 6236 | 1811 | 4643 | 4803 | 2138 | 1936 | 2400 | 1724 | 1690 | 278 | 522 |
| | (10.3) | (8.2) | (12.5) | (25.6) | (23.9) | (18.1) | (15.0) | (31.0) | (4.7) | (44.2) | (33.8) | (52.9) | (68.1) | (54.5) | (29.2) | (42.4) | (50.8) | (51.2) | (40.1) | (37.0) | (31.2) | (29.4) | (11.8) | (20.2) |
| Cladocera | 0 | 0 | 0 | 0 | 0 | 28 | 8 | 0 | 40 | 8 | 40 | 208 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.9) | (0.2) | (0.0) | (1.1) | (0.2) | (1.5) | (2.8) | (0.2) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Ostracoda | 134 | 186 | 181 | 208 | 156 | 220 | 204 | 172 | 176 | 180 | 124 | 192 | 180 | 264 | 308 | 252 | 148 | 196 | 186 | 248 | 244 | 220 | 130 | 166 |
| | (7.9) | (6.4) | (7.8) | (6.2) | (4.5) | (6.7) | (4.6) | (4.4) | (4.8) | (4.0) | (4.8) | (2.6) | (2.3) | (2.3) | (5.0) | (2.3) | (1.6) | (4.7) | (3.9) | (3.8) | (4.4) | (3.8) | (5.5) | (6.4) |
| Chaetognatha | 132 | 434 | 337 | 156 | 102 | 343 | 194 | 134 | 394 | 288 | 376 | 422 | 169 | 556 | 613 | 893 | 603 | 379 | 737 | 1216 | 1467 | 1471 | 569 | 597 |
| | (7.7) | (15.0) | (14.6) | (4.6) | (2.9) | (10.4) | (4.4) | (3.4) | (10.8) | (6.4) | (14.5) | (5.7) | (2.1) | (4.9) | (9.9) | (8.2) | (6.4) | (9.1) | (15.3) | (18.8) | (26.6) | (25.6) | (24.1) | (23.0) |
| Appendicularia | 4 | 17 | 2 | 14 | 36 | 24 | 12 | 16 | 24 | 40 | 32 | 20 | 8 | 44 | 64 | 48 | 0 | 0 | 30 | 8 | 20 | 20 | 4 | 4 |
| | (0.2) | (0.6) | (0.1) | (0.4) | (1.0) | (0.7) | (0.3) | (0.4) | (0.7) | (0.9) | (1.2) | (0.3) | (0.1) | (0.4) | (1.0) | (0.4) | (0.0) | (0.0) | (0.6) | (0.1) | (0.4) | (0.4) | (0.2) | (0.2) |
| Others | 126 | 390 | 313 | 180 | 192 | 90 | 339 | 66 | 178 | 20 | 168 | 69 | 249 | 606 | 1348 | 1602 | 138 | 59 | 72 | 102 | 238 | 289 | 105 | 31 |
| | (7.4) | (13.4) | (13.5) | (5.3) | (5.5) | (2.7) | (7.6) | (1.7) | (4.9) | (0.5) | (6.5) | (0.9) | (3.1) | (5.3) | (21.7) | (14.6) | (1.5) | (1.4) | (1.5) | (1.6) | (4.3) | (5.0) | (4.5) | (1.2) |

**Appendix 2**. Individual numbers (per haul) of the eight major zooplankton groups at the station in the central part of Toyama Bay during the period from February 1990 to January 1991. Numbers in parentheses denote their relative abundance in percentages to the total.

| Sampling date | 1990 | | | | | | | | | | | | | | | | | | | | | | 1991 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb. | | | Mar. | Apr. | | May. | | Jun. | | Jul. | | Aug. | | | Sep. | | Oct. | | Nov. | | Dec. | Jan. | |
| | 1 | 14 | 28 | 17 | 3 | 16 | 1 | 14 | 3 | 15 | 2 | 17 | 1 | 20 | 30 | 3 | 17 | 2 | 15 | 1 | 15 | 5 | 16 | 30 |
| Vol. of sea water filtered (m³) | 82.9 | 88.1 | 77.4 | 81.9 | 69.9 | 75.5 | 81.7 | 79.4 | 83.4 | 78.4 | 79.0 | 86.0 | 79.8 | 79.6 | 81.7 | 88.1 | 80.0 | 75.3 | 78.2 | 80.2 | 80.0 | 84.8 | 82.6 | 80.1 |
| Total wet wt. | 3025 | 7315 | 10509 | 18494 | 19382 | 17316 | 19062 | 18862 | 23756 | 14068 | 10789 | 16958 | 9827 | 14510 | 14811 | 15623 | 12121 | 8216 | 9858 | 13111 | 10561 | 10275 | 4572 | 4633 |
| Copepoda | 1870 | 3985 | 4358 | 7895 | 10439 | 13217 | 15421 | 16278 | 19742 | 10709 | 7923 | 8179 | 6435 | 7860 | 8372 | 8382 | 6831 | 5126 | 6082 | 9208 | 7022 | 6941 | 2903 | 2826 |
| | (61.8) | (54.5) | (41.5) | (42.7) | (53.9) | (76.3) | (80.9) | (86.3) | (83.1) | (76.1) | (73.4) | (48.2) | (65.5) | (54.2) | (56.5) | (53.7) | (56.4) | (62.4) | (61.7) | (70.2) | (66.5) | (67.6) | (63.5) | (61.0) |
| Amphipoda | 93 | 122 | 73 | 113 | 77 | 72 | 831 | 261 | 685 | 145 | 105 | 563 | 116 | 1616 | 550 | 457 | 1210 | 109 | 230 | 99 | 77 | 55 | 61 | 197 |
| | ( 3.1) | ( 1.7) | ( 0.7) | ( 0.6) | ( 0.4) | ( 0.4) | ( 4.4) | ( 1.4) | ( 2.9) | ( 1.0) | ( 1.0) | ( 3.3) | ( 1.2) | (11.1) | ( 3.7) | ( 2.9) | (10.0) | ( 1.3) | ( 2.3) | ( 0.8) | ( 0.7) | ( 0.5) | ( 1.3) | ( 4.3) |
| Euphausiacea | 25 | 52 | 2225 | 4551 | 5335 | 1200 | 577 | 532 | 543 | 364 | 139 | 382 | 845 | 946 | 296 | 689 | 735 | 349 | 319 | 326 | 223 | 221 | 44 | 75 |
| | ( 0.8) | ( 0.7) | (21.2) | (24.6) | (27.5) | ( 6.9) | ( 3.0) | ( 2.8) | ( 2.3) | ( 2.6) | ( 1.3) | ( 2.3) | ( 8.6) | ( 6.5) | ( 2.0) | ( 4.4) | ( 6.1) | ( 4.3) | ( 3.2) | ( 2.5) | ( 2.1) | ( 2.2) | ( 1.0) | ( 1.6) |
| Cladocera | 0 | 0 | 0 | 4 | 112 | 448 | 52 | 100 | 808 | 104 | 532 | 5172 | 616 | 88 | 212 | 288 | 80 | 106 | 74 | 12 | 16 | 0 | 0 | 0 |
| | ( 0.0) | ( 0.0) | ( 0.0) | ( + ) | ( 0.6) | ( 2.6) | ( 0.3) | ( 0.5) | ( 3.4) | ( 0.7) | ( 4.9) | (30.5) | ( 6.3) | ( 0.6) | ( 1.4) | ( 1.8) | ( 0.7) | ( 1.3) | ( 0.8) | ( 0.1) | ( 0.2) | ( 0.0) | ( 0.0) | ( 0.0) |
| Ostracoda | 942 | 1023 | 1150 | 1418 | 1016 | 1164 | 1096 | 1008 | 1048 | 1128 | 860 | 1164 | 1104 | 1900 | 2132 | 2076 | 1220 | 1534 | 1244 | 1780 | 1480 | 1108 | 1094 | 1190 |
| | (31.1) | (14.0) | (10.9) | ( 7.7) | ( 5.2) | ( 6.7) | ( 5.8) | ( 5.3) | ( 4.4) | ( 8.0) | ( 8.0) | ( 6.9) | (11.2) | (13.1) | (14.4) | (13.3) | (10.1) | (18.7) | (12.6) | (13.6) | (14.0) | (10.8) | (23.9) | (25.7) |
| Chaetognatha | 44 | 61 | 48 | 51 | 59 | 113 | 37 | 31 | 92 | 94 | 250 | 509 | 294 | 825 | 1229 | 1873 | 1472 | 725 | 1033 | 1056 | 903 | 1407 | 262 | 163 |
| | ( 1.5) | ( 0.8) | ( 0.5) | ( 0.3) | ( 0.3) | ( 0.7) | ( 0.2) | ( 0.2) | ( 0.4) | ( 0.7) | ( 2.3) | ( 3.0) | ( 3.0) | ( 5.7) | ( 8.3) | (12.0) | (12.1) | ( 8.8) | (10.5) | ( 8.1) | ( 8.6) | (13.7) | ( 5.7) | ( 3.5) |
| Appendicularia | 35 | 284 | 452 | 194 | 784 | 280 | 112 | 212 | 528 | 1408 | 920 | 704 | 156 | 536 | 828 | 828 | 364 | 54 | 552 | 304 | 312 | 212 | 102 | 156 |
| | ( 1.2) | ( 3.9) | ( 4.3) | ( 1.1) | ( 4.0) | ( 1.6) | ( 0.6) | ( 1.1) | ( 2.2) | (10.0) | ( 8.5) | ( 4.2) | ( 1.6) | ( 3.7) | ( 5.6) | ( 5.3) | ( 3.0) | ( 0.7) | ( 5.6) | ( 2.3) | ( 3.0) | ( 2.1) | ( 2.2) | ( 3.4) |
| Others | 16 | 1788 | 2203 | 4268 | 1560 | 822 | 936 | 441 | 310 | 116 | 60 | 285 | 261 | 739 | 1192 | 1030 | 209 | 213 | 324 | 326 | 528 | 331 | 106 | 26 |
| | ( 0.5) | (24.4) | (21.0) | (23.1) | ( 8.1) | ( 4.8) | ( 4.9) | ( 2.3) | ( 1.3) | ( 0.8) | ( 0.6) | ( 1.7) | ( 2.7) | ( 5.1) | ( 8.1) | ( 6.6) | ( 1.7) | ( 2.6) | ( 3.3) | ( 2.5) | ( 5.0) | ( 3.2) | ( 2.3) | ( 0.6) |

+ : <0.1%

**Appendix 3**. Individual numbers (per 100 m$^3$) of copepods at the station in the central part of Toyama Bay during the period from February 1 to June 3 in 1990.

| Species | February | | | March | April | | May | | June |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 14 | 28 | 17 | 3 | 16 | 1 | 14 | 3 |
| *Calanus pacificus* s.l. | 14 | 47 | 78 | 63 | 326 | 456 | 847 | 398 | 585 |
| *C. minor* | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 0 | 0 |
| *Neocalanus plumchrus* | 21 | 9 | 23 | 31 | 0 | 0 | 20 | 0 | 0 |
| *N. cristatus* | 21 | 5 | 11 | 0 | 0 | 1 | 5 | 1 | 0 |
| *Mesocalanus tenuicornis* | 67 | 239 | 125 | 231 | 1196 | 1059 | 586 | 196 | 0 |
| *Eucalanus bungii bungii* | 0 | 0 | 0 | 0 | 60 | 39 | 54 | 25 | 1 |
| *Paracalanus* sp. | 5 | 892 | 103 | 839 | 673 | 549 | 234 | 147 | 44 |
| *Clausocalanus arcuicornis* | 0 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *C. pergens* | 0 | 102 | 171 | 231 | 239 | 118 | 39 | 0 | 88 |
| *Ctenocalanus vanus* | 88 | 93 | 103 | 105 | 30 | 0 | 39 | 0 | 44 |
| *Pseudocalanus minutus* | 237 | 325 | 228 | 304 | 329 | 157 | 39 | 49 | 44 |
| *P. newmani* | 5 | 65 | 34 | 84 | 269 | 39 | 312 | 49 | 0 |
| *Gaidius variabilis* | 46 | 74 | 68 | 52 | 90 | 0 | 83 | 64 | 107 |
| *Gaetanus* sp. | 10 | 5 | 11 | 0 | 0 | 0 | 5 | 0 | 0 |
| *Pareuchaeta japonica* | 119 | 218 | 125 | 251 | 314 | 210 | 241 | 141 | 215 |
| *Scolecithricella dentata* | 124 | 42 | 46 | 136 | 209 | 39 | 0 | 0 | 0 |
| *S. minor* | 289 | 242 | 171 | 336 | 239 | 196 | 469 | 391 | 395 |
| *Centropages abdominalis* | 0 | 5 | 0 | 63 | 15 | 0 | 0 | 0 | 0 |
| *C. bradyi* | 46 | 70 | 34 | 10 | 15 | 0 | 39 | 49 | 88 |
| *C. yamadai* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 |
| *Metridia pacifica* | 589 | 1086 | 3035 | 3260 | 4773 | 1976 | 2037 | 1607 | 1362 |
| *Pleuromamma gracilis* | 83 | 167 | 23 | 73 | 60 | 78 | 0 | 0 | 0 |
| *Lucicutia flavicornis* | 52 | 33 | 11 | 42 | 120 | 0 | 0 | 0 | 0 |
| *Candacia bipinnata* | 5 | 0 | 0 | 10 | 0 | 39 | 5 | 0 | 0 |
| *Acartia danae* | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *A. omorii* | 0 | 5 | 11 | 84 | 105 | 78 | 0 | 98 | 0 |
| *Oithona atlantica* | 356 | 581 | 1094 | 3190 | 5635 | 11765 | 13042 | 16675 | 19319 |
| *O. plumifera* | 5 | 28 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| *O. similis* | 21 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Oncaea conifera* | 10 | 5 | 0 | 73 | 120 | 78 | 0 | 0 | 0 |
| *O. media* | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *O. mediterranea* | 21 | 46 | 34 | 42 | 15 | 0 | 39 | 25 | 19 |
| *Corycaeus affinis* | 21 | 33 | 80 | 126 | 105 | 627 | 703 | 587 | 1317 |