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Article

Seasonal Variation of Phytoplankton and Zooplankton Communities in the Coastal Waters off Tongyeong in Korea

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Abstract : To investigate the community structures and the their seasonal variation of phytoplankton and zooplankton, a study was conducted at 6 selected stations during the period from April 1999 to October 2000 in the marine ranching ground off Tongyeong. One hundred ninety species of phytoplankton were identified, including 146 diatoms, 38 dinoflagellates, 4 silicoflagellates and 2 euglenophytes. Phytoplankton standing crops varied extensively by months and stations, ranging from 3.0×10^4 cells/*l* to 1.0×10^6 cells/*l*. The dominant species varied from the vertical distribution as well as seasonal changes. In April and July 1999, *Skeletonema costatum* and *Ceratium fusus* were predominant in both the surface and the bottom water columns. *Leptocylindrus danicus* was the dominant species in April and June 2000, and *Thalassiosira* spp. were also predominant in bottom waters in June 2000. *Pseudonitzschia pungens* and *Chaetoceros* spp. were the dominant species at both surface and near bottom waters in August and October 2000, respectively.

Zooplankton abundance was comparatively high in April and July in 1999, and April, June, and October in 2000, but extremely low in November 1999. The density of dominant zooplankton was higher in 2000 than in 1999. Copepods were the most predominant group except for July 1999 when the bivalve larvae showed extremely high abundance. *Acartia omorii* and *Oithona similis* were the dominant or subdominant copepod species mainly in April 2000, and June/July, while *O. davisae* and *O. plumifera* had peaks in August and October 2000. *Corycaeus affinis* and *Paracalanus* sp. also showed higher peaks in April and June (or July), even though they occurred in all sampling time. *Centropages abdominalis* occurred abundantly only in April 1999. *Oikopleura dioica*, a gelatinous zooplankton, was another important zooplankton, showing high density in all samples except in July 1999.

Key words : abundance, community structure, density, phytoplankton, seasonal variation, zooplankton.

1. Introduction

The energy flow through biotic components in a marine ecosystem starts, in general, at photosynthetic organisms which convert inorganic compounds into organic compounds using solar energy. Phytoplankton, in which diatoms and dinoflagellates are predominant species, is the important primary producer in a classical food web, and grazed usually by metazoan zooplankton. Zooplankton also plays an important role in transfering energy to higher trophic levels, because they are not only grazers on phytoplankton but also food source for many small carnivorous invertebrates and fishes. Thus, zooplankton probably largely control the abundance of fishes and invertebrates which include the local fishery resources. Understanding the structures of phyto- and zooplankton community may provide basic knowledge for monitoring the ecological capacity for sustainable production of a marine ranching ground.

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Coastal waters off Tongyeong, where the marine ranching ground is located, have been known to be less polluted compared to the other southern coastal waters of Korea which have been often eutrophicated by increased industrial complexes and population, and agricultural waste waters. Studies on the compositions and distributional patterns of phyto- and zooplankton in the coastal waters around Korea have been intensively investigated (Park 1980; Kim *et al.* 1993). However, little information is available in the waters around Tongyeong except for the studies conducted through the marine ranching program.

This study deals with species composition, abundance and their seasonal variation of phyto- and zooplankton at 6 selected stations in the marine ranching ground off Tongyeong during the period from April 1999 to October 2000.

2. Material and methods

Phytoplankton

Samples were seasonally collected from the surface and near the bottom using a Niskin bottle during the period from April 1999 to October 2000 (Fig. 1). Water temperature and salinity were measured simultaneously. One liter of seawater was fixed with 5 % neutralized formalin on board, then plankton were concentrated by settling them in 150-200 m*l* bottles in the laboratory for identification. Quantitative analyses of the phytoplankton was made by placing 0.5 m*l* of the concentrated samples in Rafter-Sedgwick Counting Chamber and counting all specimens. All counts were expressed as phytoplankton standing crops of the cells per litre. In order to identify phytoplankton samples more precisely, specimens were observed in permanent mounts under LM and SEM (Jeol 5600LV, Sangmyung University) after cleaning off organic matters (Hasle and Fryxell 1970; Hasle 1983).

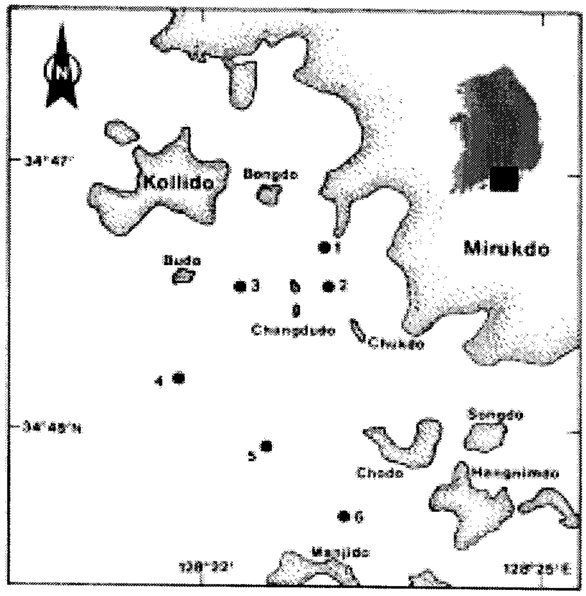

Fig. 1. Map showing the sampling stations in the coastal waters off Tongyeong.

Zooplankton

Samples were collected simultaneously with phytoplankton at the same sampling stations. Two different plankton nets were used for samplings in 1999, and both nets were of a conical type with mouth diameter of 0.6 m, of which mesh aperture was 300 μm and 60 μm, respectively. The smaller aperture net was used for better estimation of abundance in smaller zooplankton (Böttger-Schnack 1990a, b), while the 150 μm or bigger mesh aperture net has been commonly used for collecting samples in coastal area (Kim *et al.* 1993). After examination a comparison among of samples from April 2000 which were collected with three different nets of mesh aperture, 60 μm, 100 μm, and 300 μm, a maximum of zooplankton abundance was found from 100 μm. Thus, a 100 μm net of same type with those of 1999 was considered to be the most adequate sampling net, and chosen in collection in 2000. We calculated the water volume filtered by net with a flow-meter equipped in front of the net mouth. To minimize the quantitative error caused by patch distribution of zooplankton (Ueda 1987; Ambler *et al.* 1991), collections were made more than three times per collection. Zooplankton samples were identified and counted under a dissecting microscope (SV11, Zeiss and SZ60, Olympus), after divided different groups with a Folsom typed splitter. When necessary, some specimen were dissected in lactic acid or glycerol for exact identification, stained with Chlorazol black E or fast-green, then observed under a microscope (Axioplan, Zeiss).

3. Results and discussion

Changes in water temperature and salinity

The lowest water temperature was recorded in April in both years during the study period, while the highest was observed in July in 1999 and August in 2000, respectively. The temperature difference between the surface and bottom waters was probably caused by surface heating from sunlight, because sampling was made generally during the day. Water temperature was also variable among stations in summer, while the surface temperature of August 2000 was exceptional. Salinity data showed no evidence of any strong impacts of fresh water input, while comparatively lower salinity of July in 1999, and August and October 2000 was probably caused by precipitation.

Species composition of phytoplankton

A total of 190 species of phytoplankton, composed of 146 diatoms, 38 dinoflagellates, 4 silicoflagellates and 2 euglenophytes, were identified. In the surface waters, 116 diatoms, 29 dinoflagellates, 4 silicoflagellates and 1 euglenoid species were observed, while 132 diatoms, 24 dinoflagellates, 3 silicoflagellates and 2 euglenoids were observed at the bottom water samples. Number of the species changed monthly from minimal 47 species out of the surface in November 1999 to maximal 82 species from the bottom in July 1999. The data indicated that the species diversity was very high during the study periods, thus long-term investigations should be conducted in details for better understanding of the succession of the highly diverse phytoplankton community. Among the phytoplankton communities observed, *Chaetoceros curvisetus*, *C. debilis*, *C. decipiens*, *Leptocylindrus danicus*, *Pseudonitzschia delicatissima*, *P. pungens*, and *Thalassionema nitzschioides* occurred every month in the surface waters, while *Chaetoceros danicus*, *C. debilis*, *C. socialis*, *Cylindrotheca closterium*, *Leptocylindrus danicus*, *L. minimus*, *Pseudonitzschia delicatissima*, *P. pungens*, *Rhizosolenia setigera*, and *Thalassionema nitzschioides* were identified in the bottom waters. These 12 species were representative in terms of occurrence frequency in this area.

Even though there are very few studies were carried out on phytoplankton communities in the coastal waters off Tongyeong, KORDI (1998) reported that the red-tides in the study area were caused mainly by 2 protozoans, 7 diatoms and 12 flagellates species from 1990. Among them, outbreaks of *Cochlodinium polykrikoides* have been observed since 1993 and brought enormous damages to fisheries. During the time of survey for this study, however, red-tides were not observed.

Standing crops of phytoplankton

Phytoplankton standing crops varied extensively by months and stations, ranging from 3.0×10^4 cells/*l* at St. 3-B in July 1999 to 2.6×10^6 cells/*l* at St. 1-S in October 2000. Horizontal distribution of phytoplankton standing crops varied from stations to stations. Vertical distribution showed higher density of phytoplankton cells in surface waters in most samples. The highest peaks in standing crops were observed in April 1999 and October 2000, respectively, while the density was also a little higher in April and June than that in August 2000. As shown in Fig. 3, phytoplankton was denser at outer stations (St. 4-6) in April 1999, while the highest was recorded at surface waters of St. 1 in 2000, respectively. In general, phytoplankton standing crops in this study were lower than those of neighboring coastal areas; phytoplankton standing crops ranged between $1.2\text{-}5.2\times10^5$ cells/*l* in the vicinity of Wando Islands (Yoo and Hue 1982), $5.8\times10^4\text{-}5.9\times10^6$ cells/*l* in the coastal waters adjacent to Samchonpo Thermal Power Plant (Kim *et al.* 1993), with an annual mean of 3.3×10^5 cells/*l* in Gwangyang Bay (Cho *et al.* 1994), and $2.6\times10^3\text{-}1.0\times10^6$ cells/*l* in Deukryang Bay (Yoon 1999). Shim and Lee (1984) investigated a relative importance of nanoplankton in the vicinity of Chungmu Harbor, where netplankton standing crops varied from 7.7×10^5 cells/*l* to $2.0\text{-}4.6\times10^6$ cells/*l* in the surface layer, and that of nanoplankton ranged from 5.0×10^5 cells/*l* to 4.3×10^6 cells/*l* in the surface waters.

Dominant species of phytoplankton

The seasonal trends of dominant species were comparatively clear (Table 1). The dominant species of April and July 1999 were *Skeletonema costatum* and *Ceratium fusus*, respectively, in both the surface and bottom waters. The dominant species in November was replaced by *Chaetoceros socialis* at St. 1, 2 and 6, and *C. diadema* at St. 3, 4 and 5 in the surface waters, while those from the bottom waters were composed of various species. *Skeletonema costatum* in April 1999 was exceptionally dense, reaching $1.0\text{-}2.0\times10^5$ cells/*l* in the surface water samples. This species has been known as the most outstanding species in all of the Korean coastal waters (Yoo and Lee 1979, 1980, 1982; Park 1980; Lee *et al.* 1981; Lee and Huh 1983; Lee and Byun 1991; Lee 1994; Lee *et al.* 1997), with a maximum population reaching 1.17×10^7 cells/*l* in November 1978 in Jinhae Bay (Lee *et al.* 1981). *Ceratium fusus* had a relatively lower cell density in July 1999 during this study period, whereas a red-tide speices of *Ceratium fusus* was recorded in August 1981 in Jindong Bay, the neighbouring waters to the study area, and its density was 2.1×10^5 cells/*l* (Lee 1994). *Leptocylindrus danicus* was the dominant species in both the surface and bottom waters in April and June 2000, but the cell density was not high. Abundant density of *L. danicus*, a causative organism of blooms, was observed in the southern coastal waters of Korea in spring (Yoo and Lee 1976; Yoo and Lee 1979, 1980). A bloom of *L. danicus* was closely related to the gradient of salinity in Masan Bay (Yoo and Lee 1976), while those in

Table 1. Seasonal changes of phytoplankton dominant species in the waters off Tongyeong.

Month	Stn.	Surface	%	Bottom	%
1999 April	1	*Skeletonema costatum*	45.6	*Skeletonema costatum*	54.2
	2	*Skeletonema costatum*	51.4	*Skeletonema costatum*	62.5
	3	*Skeletonema costatum*	43.0	*Skeletonema costatum*	53.1
	4	*Skeletonema costatum*	62.6	*Skeletonema costatum*	52.3
	5	*Skeletonema costatum*	49.6	*Skeletonema costatum*	61.7
	6	*Skeletonema costatum*	54.1	*Skeletonema costatum*	57.4
July	1	*Ceratium fusus*	34.2	*Ceratium fusus*	52.3
	2	*Ceratium fusus*	37.5	*Ceratium fusus*	27.4
	3	*Ceratium fusus*	30.6	*Ceratium fusus*	34.5
	4	*Ceratium fusus*	48.4	*Ceratium fusus*	54.3
	5	*Ceratium fusus*	45.5	*Skeletonema costatum*	30.1
	6	*Ceratium fusus*	32.0	*Ceratium fusus*	43.0
November	1	*Chaetoceros socialis*	43.1	*Skeletonema costatum*	22.8
	2	*Chaetoceros socialis*	30.5	*Chaetoceros diadema*	35.0
	3	*Chaetoceros diadema*	28.2	*Skeletonema costatum*	26.2
	4	*Chaetoceros diadema*	65.5	*Chaetoceros debilis*	26.7
	5	*Chaetoceros diadema*	27.1	*Chaetoceros diadema*	49.3
	6	*Chaetoceros socialis*	36.0	*Paralia sulcata*	16.5
2000 April	1	*Leptocylindrus danicus*	67.88	*Leptocylindrus danicus*	67.59
	2	*Leptocylindrus danicus*	70.94	*Leptocylindrus danicus*	64.43
	3	*Leptocylindrus danicus*	60.97	*Leptocylindrus danicus*	74.27
	4	*Leptocylindrus danicus*	71.83	*Leptocylindrus danicus*	25.54
	5	*Leptocylindrus danicus*	67.30	*Leptocylindrus danicus*	63.39
	6	*Leptocylindrus danicus*	67.34	*Leptocylindrus danicus*	73.50
June	1	*Chaetoceros decipiens*	27.3	*Leptocylindrus danicus*	16.9
	2	*Leptocylindus danicus*	31.1	*Chaetoceros decipiens*	23.7
	3	*Leptocylindus danicus*	28.3	*Thalassiosira spp.*	14.4
	4	*Leptocylindus danicus*	26.8	*Chaetoceros decipiens*	16.0
	5	*Leptocylindus danicus*	16.1	*Leptocylindrus danicus*	32.9
	6	*Leptocylindus danicus*	16.9	*Leptocylindrus danicus*	11.8
August	1	*Pseudonitzschia pungens*	17.3	*Pseudonitzschia pungens*	42.5
	2	*Chaetoceros laciniosus*	18.6	*Pseudonitzschia pungens*	61.2
	3	*Pseudonitzschia pungens*	16.9	*Pseudonitzschia pungens*	50.8
	4	*Chaetoceros teres*	17.9	*Pseudonitzschia pungens*	51.6
	5	*Chaetoceros laciniosus*	42.1	*Dictyocha speculum*	18.9
	6	*Pseudonitzschia pungens*	18.0	*Pseudonitzschia pungens*	29.5
October	1	*Chaetoceros socialis*	47.7	*Chaetoceros socialis*	33.2
	2	*Chaetoceros socialis*	37.5	*Chaetoceros curvisetus*	40.0
	3	*Chaetoceros socialis*	40.7	*Chaetoceros socialis*	43.4
	4	*Chaetoceros curvisetus*	27.4	*Skeletonema costatum*	54.6
	5	*Chaetoceros curvisetus*	25.0	*Skeletonema costatum*	44.4
	6	*Skeletonema costatum*	34.9	*Skeletonema costatum*	41.6

April and June 2000 in this study showed little relationship between them. In August 2000, *Pseudonitzschia pungens* and *Chaetoceros laciniosus* were the most dominant species, while the densities of both species were not high compared to other seasons. In October 2000, *Chaetoceros socialis* and *C. curvisetus* were predominant in the surface waters of all stations except for St. 6, while at the near bottom waters, they are dominant only in inner stations, and *Skeletonema costatum* was the dominant species in outer stations.

Distributional pattern and seasonal variation of zooplankton

Fig. 4 showed spatial and seasonal variation of main mesozooplankton. In the three sets of collections in 1999, a higher density sample of the results for the both of the 60 μm and 300 μm nets was chosen. The most predominant group was copepods at all six stations in April 1999, showing

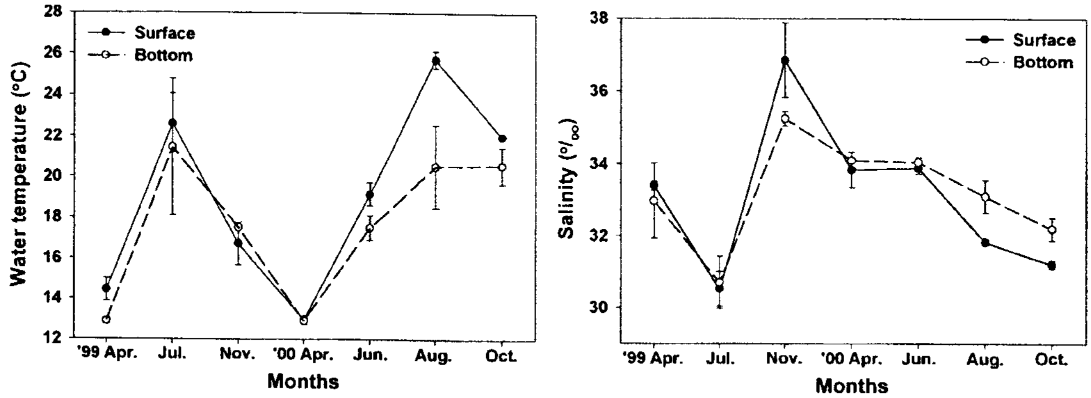

Fig. 2. Water temperature and salinity in the coastal waters off Tongyeong from April in 1999 to October in 2000.

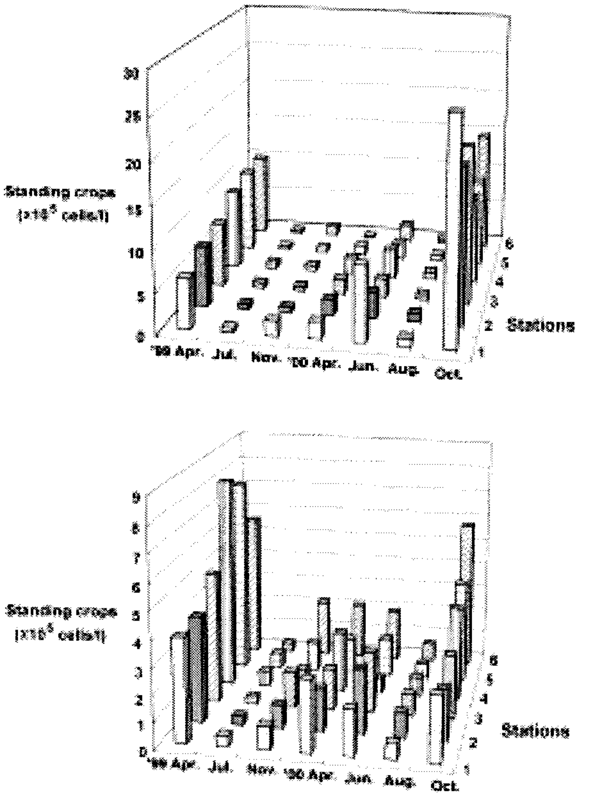

Fig. 3. Seasonal variation of phytoplankton standing crops in the coastal waters off Tongyeong from April in 1999 to October in 2000 (upper: surface layer, lower: bottom layer).

little variation among the stations. Fourteen species of copepods were identified, and the density of total adults and juveniles ranged from 7,269 to 10,933 inds m^{-3}. Dominant species of adult copepods were *Acartia omorii, Centropages abdominalis, Paracalanus* sp., and *Oithona similis* (Fig. 5). Adult copepods, which were maximally collected with 300 m net except for those of *O. similis* and *Paracalanus* sp., sometimes showed a little contribution to total copepod density. While, copepod juvuniles, nauplii and copepodites were in great numbers in abundance of all copepod, ranging from 3,750 to 6,981 ind m^{-3} and from 904 to 1,921 ind m^{-3}, respectively. All of dominant species of adults showed insignificant change in density among the stations, while copepod nauplii occurred with higher density at St. 1 and 6, and copepodites at St. 2, 3, and 6. The differences in density between the highest and the lowest were approximately twice. Subdominant groups were *Oikopleura dioica* and non-copepod crustacean larvae such as barnacle nauplii and decapod zoea.

Bivalve larvae showed extremely high density in July 1999, ranging from 8,540 to 12,054 ind m^{-3}, while copepod density was lower in July than that in April, ranging from 2,429 to 4,290 ind m^{-3} (Fig. 4). Copepod nauplii were the most predominant, and non-calanoid copepod such as *Oithona* spp. and *Corycaeus* spp. were the dominant species among adults and copepodites. Subdominant group of another crustaceans was barnacle nauplii, ranging from 912 to 3,240 ind m^{-3}, a little higher than April.

Zooplankton density in November was much lower than that in April and July. Copepods were still dominant group, while the density was below 800 ind m^{-3} in most stations (Fig. 4). Density of copepod nauplii in November was also low compared to that in April and July, whereas they contributed largely to total zooplankton abundance in November. Lower density of copepod nauplii may indicate that the low production of the animals in cold season. *Paracalanus* sp. was the dominant species among adult copepods in this season, and denser in outer stations. *Oikopleura dioica* was also dominant, increased slightly from July (Fig. 5).

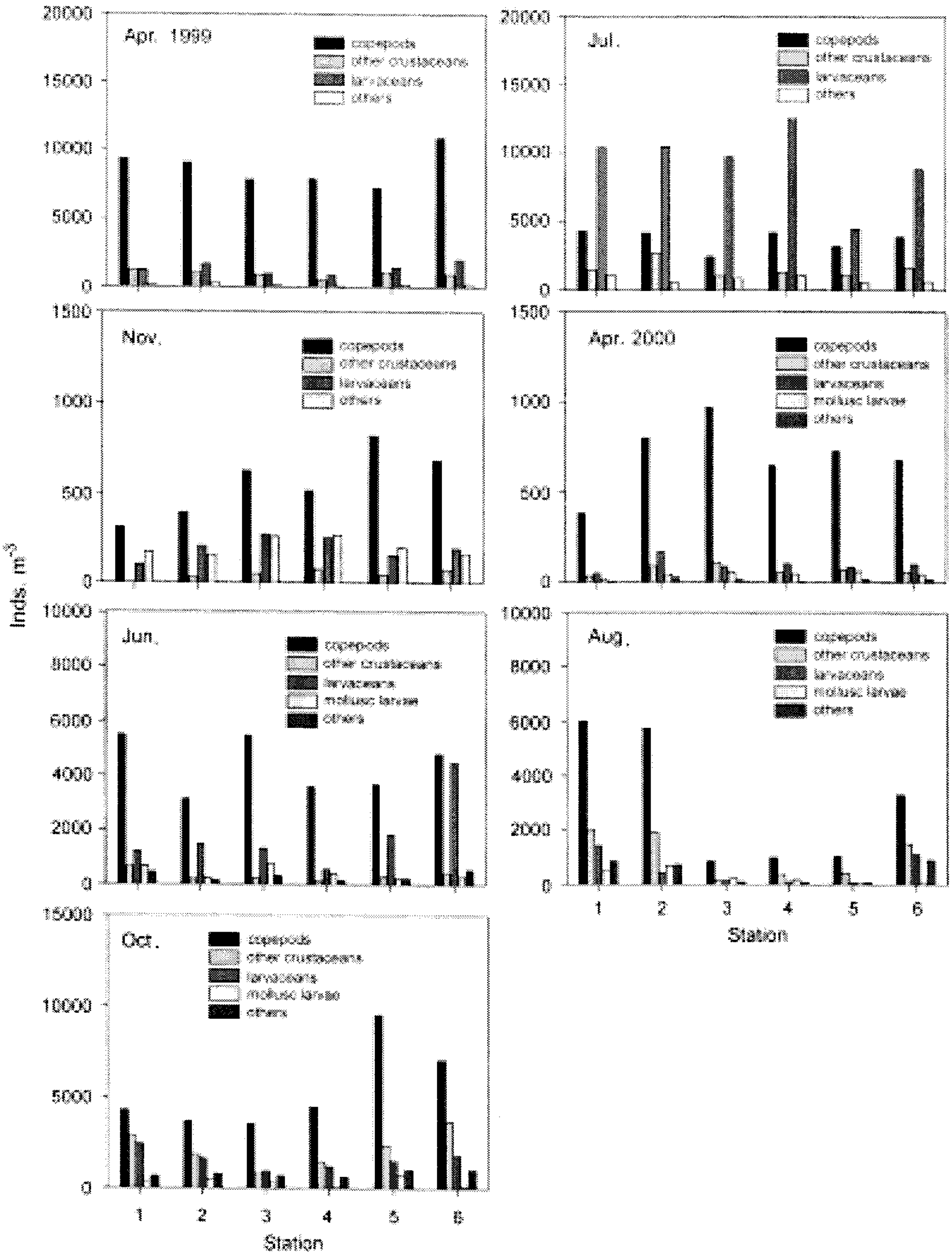

Fig. 4. Abundance of major zooplankton groups in the coastal waters off Tongyeong from April in 1999 to October in 2000.

The total mesozooplankton density in April 2000 was recovered to the same level of 1999 (Fig. 4). Dominant adult copepods showed higher density, while nauplii density was lower, and the lower density of the juveniles might be caused by the net with coarser mesh used in 2000. Smaller copepods, *Oithona similis* and *Paracalanus* sp. were the most important species in terms of density, while *Acartia omorii*, *Centropages abdominalis* and *Corycaeus affinis* also showed increased density compared to those of 1999. Two species of cladocerans were also high in density. Barnacle nauplii and *Oikopleura dioica* were the subdominant animal groups.

Bivalve larvae showed high density in June 2000, whereas it was not extreme as July 1999. Cladocerans still showed high levels of density, while never exceeded to that of copepods (Fig. 4). Among the copepods, *Paracalanus* sp. and *Oithona similis* showed higher density than those of 1999. *Oikopleura dioica* also showed high level of individual density. Another subdominant group was barnacle nauplii.

The most dominant species of zooplankton in August 2000 were *Oithona similis, O. davisae, Paracalanus crssirostris,* and *Paracalanus* sp. among the copepods. A cladocera, *Evadne tergestina*, mollusc larvae and *Oikopleura dioca* were other dominant zooplankton groups (Figs. 4, 5). Much higher density of copepods at inner sampling stations, St. 1 and 2, was mainly caused by restricted distribution of *O. davisae* at the inlet area, while *O. similis* showed little variation in abundance among the stations.

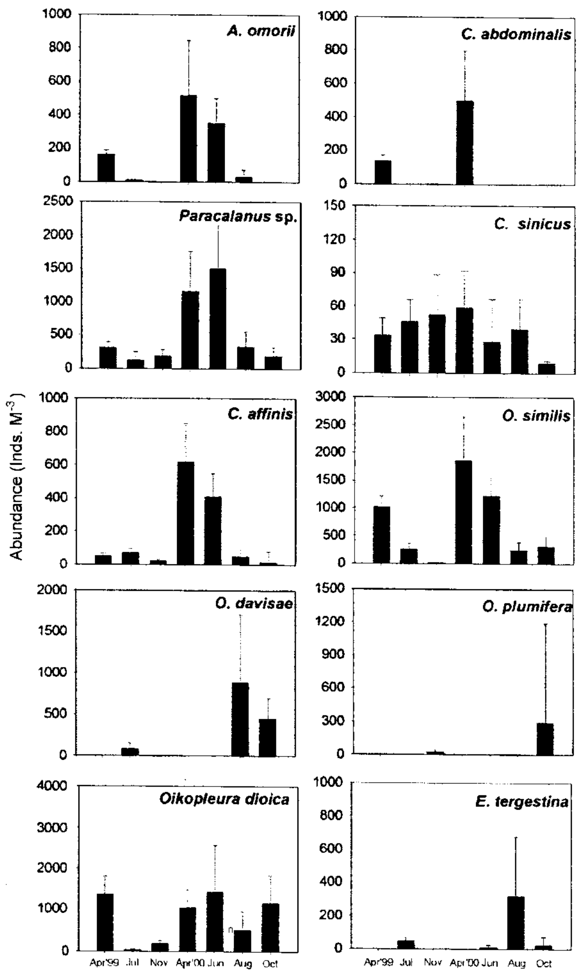

Fig. 5. Seasonal variation in abundance of dominant species or groups of zooplankton in the coastal waters off Tongyeong from April in 1999 to October in 2000.

In October 2000, copepods such as *Oithona* spp. and *Paracalanus* spp., mollusc larvae and *Oikopleura dioca* were the predominant groups, while cladocerans showed comparatively lower density (Figs. 4, 5). Thus, *Oithona* spp. and *Paracalanus* spp. were dominant copepods in all sampling periods, while density of *Acartia omorii* and *Centropages abdominlais* were abundant in April and June or only in April, respectively. Barnacle nauplii and *Oikopleura dioica* were very important zooplankton species among non-copepod taxa in this area in almost all season, which showed very similar patterns to that of copepods in seasonal variation. Bivalve larvae showed an eventual peak in July 1999, while observed in both spring and summer.

Copepods are the most abundant zooplankton in the southern waters of Korea and their abundance and distribution have been well studied (Kim *et al.* 1993). Those studies often showed broad ranges of temporal variation in abundance (Kim 1984; KORDI 1980; Lee 1989; Shim and Ro 1982). In many studies, copepod juveniles have not been represented independently. From the data on abundance of dominant adult copepods, the results of this study showed median abundance and stable diversity of copepods compared to other waters of the southern coastal area of Korea.

Copepods, as a whole, were the most abundant in April, then showed minimal abundance in November in 1999. They showed the same trend of seasonal variation while the density was a little higher in October than in August in 2000. Among the studies on seasonal variation of copepods

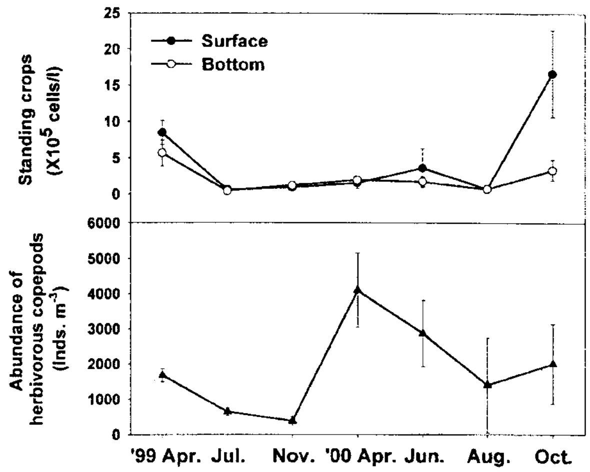

Fig. 6. Changes in abundance of phytoplankton and zooplankton in the coastal waters off Tongyeong from April in 1999 to October in 2000.

in the southern inlet waters off Korea, Masan Bay showed bimodal peaks of the zooplankton abundance in April and October (Lee 1972; Lee 1989), while other areas in southern waters in general tend to show unimodal biomass peak in fall (Kang and Lee 1991; Kim *et al.* 1993). Even though sampling interval of this study was quite long for clear understanding of the temporal variation, only a unimodal peak was observed in spring when diatom biomass was the highest in 1999. Even though the seasonal variation of copepod abundance in 2000 was not large compared to that of 1999, the highest peak was also observed in April. It suggests that seasonal variation of this area is similar to that of Masan Bay or various coastal regions of the Yellow Sea (Kang and Lee 1991; Kim *et al.* 1993), where higher or one high peak of abundance exists in spring instead of fall.

Adult copepods, as a whole, were more abundant in 2000 than 1999, while the seasonal patterns were almost similar to each other. The most dominant herbivorous copepod, *Acartia omorii, Centropages abdominalis, Paracalanus* sp. and *Oithona similis* were abundant in April and July except for *O. davisae* and *O. plumifera* which were observed in August and October (Fig. 5). *Calanus sinicus* occurred in all sampling period, even though the density was comparatively low. Fig. 6 showed seasonal variation in phytoplankton standing crops and abundance of herbivorous copepods. Inverse relationship between phytoplankton and zooplankton standing stocks may be observed when zooplankton grazing is high enough to control phytoplankton abundance (Banse 1992), even though the impact of zooplankton grazing is quite variable in many areas. It is suggested that smaller peaks of standing crops in phytoplankton in April 2000 compared to that in 1999 might be caused by higher density of herbivores, and vice versa in October 2000. However, our understanding how zooplankton grazing controls phytoplankton standing crops is very limited, because zooplankton feeding rate and selectivity have not been investigated for this study area.

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