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Seasonal changes in zooplankton community in the coastal waters off Incheon

SEOK-HYUN YOUN* AND JOONG-KI CHOI
Department of Oceanography, Inha Uinversity, Incheon 402-751, Korea

The seasonal succession of zooplankton communities in the coastal area off Incheon, Kyeonggi Bay, was investigated with the samples collected at intervals of 10 to 15 days from January 1999 to December 2000. Total abundance of zooplankton communities showed remarkable seasonal variations, ranged from 1,100 to 120,400 indiv./m³, and annual mean abundance was 22,000 indiv./m³. There were several times of the total abundance during a year, and the timing ofhigh abundances were about the same in 1999 and 2000. During the study period except summer, the abundance of dinoflagellate *Noctiluca scintillans* and copepod *Acartia hongi* contributed to the most part of total zooplankton. Whereas, during summer, smaller copepod *Oithona davisae* and *Paracalanus crassirostris* were dominant species. Zooplankton communities in the coastal waters off Incheon showed typical characteristics of coastal-estuarine communities, which were dominated by a few species, and abrupt seasonal variations in abundance. We suggest that the seasonal succession and abundance variations of zooplankton communities were caused by the seasonal variations in water temperature and by the seasonally varying phytoplankton biomass in the study area.

Key words: Zooplankton Community, Incheon Coastal Waters, Seasonal Change

INTRODUCTION

The biomass and abundance of zooplankton show drastic seasonal change in temperate coastal waters and estuaries and the zooplankton is higher in abundance and lower in diversity than those of adjacent neritic waters (Colebrook, 1979; Kimmerer, 1993). Seasonal variations in abundance and biomass of zooplankton are influenced continuously by the various environmental factors such as temperature, salinity, food and predation pressure, and the relative importance of these factors varies seasonally. Therefore, for the understanding of seasonal variations in abundance of zooplankton community in the complicated coastal ecosystems, short-term period survey is required rather than typical seasonal or monthly investigation (Shim and Choi, 1996). Short-term sampling at interval of a week or longer is necessary to understand the zooplankton community structure and seasonal succession (Omori and Ikeda, 1984).

Incheon coastal waters located in inner part of Kyeonggi Bay, Yellow Sea are coastal plain estuary and its depth is approximately 10–30 m. This estuarine and coastal waters are characterized by a large tidal range up to about 9–10 m, and the tide at Incheon harbor is of semi-diurnal type. The tidal currents at Incheon outer harbor are of semi-diurnal type same as tides, and the flood and ebb currents set northeast and southwest with a velocity of about 42–175 cm/sec and 44–225 cm/sec at spring tide, respectively (Yi, 1972). This strong tidal current resuspends sediment particles and makes water column well-mixed (Choi and Shim, 1986b). Large amount of fresh water flowed from the Han River and Imjin River causes a dramatic seasonal variation in salinity. Due to shallow depth, seasonal fluctuation of water temperature also show a wide range from 1°C to 26°C (Choi and Shim, 1986a). On account of input of nutrients from fresh water and Incheon metropolitan city, high primary production could be sustained in the coastal waters (Chung and Park, 1988).

There were several studies about zooplankton ecology in Incheon coastal waters such as the distribution pattern of zooplankton community in Han River estuary (Myung, 1992), the seasonal distribution of zooplankton in Incheon dock (Kim and Lee, 1994), the seasonal

*Corresponding author: ysh1393@hanmail.net

succession of copepod community in Kyeonggi Bay (Shim and Choi, 1996), zooplankton distribution in Lake Shiwha and adjacent coastal waters (Park and Huh, 1997) and the seasonal distribution of zooplankton community in Incheon coastal waters (Yun and Choi, 1997). Most of previous studies except Shim and Choi (1996) were based on seasonal or monthly survey. These may not be appropriate to obtain the information about short-term variations of zooplankton communities. Shim and Choi (1996) briefly reported the short-term variations in abundance of copepod communities at interval of 7 to 30 day during a year. Shim (1996) introduced the methodology concerned with the short interval survey in coastal waters and studied taxonomy of *Acartia bifilosa*.

The results of two-year study of the zooplankton community in Incheon coastal waters were described in this paper. At least two-year sampling period is necessary to verify the reiterative process of seasonal succession of zooplankton community, when considering that the cycle of seasonal succession is one year. We focused on the seasonal succession of zooplankton community and seasonal variations in abundance of dominant species.

MATERIALS AND METHODS

Samples were collected at a station in Incheon coastal waters located in inner part of Kyeonggi Bay at interval of 10 to 15 day from January 1999 to December 2000. Temperature and salinity were measured with a salino-meter (YSI, Model: 30) at 1 m depth. Water samples (1,000 ml) for determination of chlorophyll-*a* concentration were collected at the surface water, then filtered with 47 mm Whatman GF/F filter. Later, the filters were extracted by 90% acetone, and fluorometrically determined (Parsons *et al.*, 1984). We assumed that the values of chlorophyll-*a* at surface water could represent those of whole water layers, due to the shallow depth and well-mixed water column in Incheon coastal waters (Choi and Shim, 1986b). Zooplankton samples were taken by vertical tows of a conical-type net (diameter: 0.45 m, length: 2 m, mesh opening: 60 μm) equipped with flow meter from the bottom to the surface. Zooplankton sampling was conducted around high tide to reduce the variability of zooplankton abundance by tidal cycle. Samples were preserved immediately with buffered formaldehyde solution (final concentration, about 4%). In the laboratory, more than 100 individuals of dominant species were subsampled and counted in Bogorov counting chamber under Olympus stereomicroscope. Zooplankters were identified into lowest practical taxon. The numbers counted were converted into individual numbers per unit volume (Indiv./m^3), and the significant figures of abundance were described by the hundreds. Copepod nauplii and ciliates were not counted since they were not retained quantitatively by the net we used.

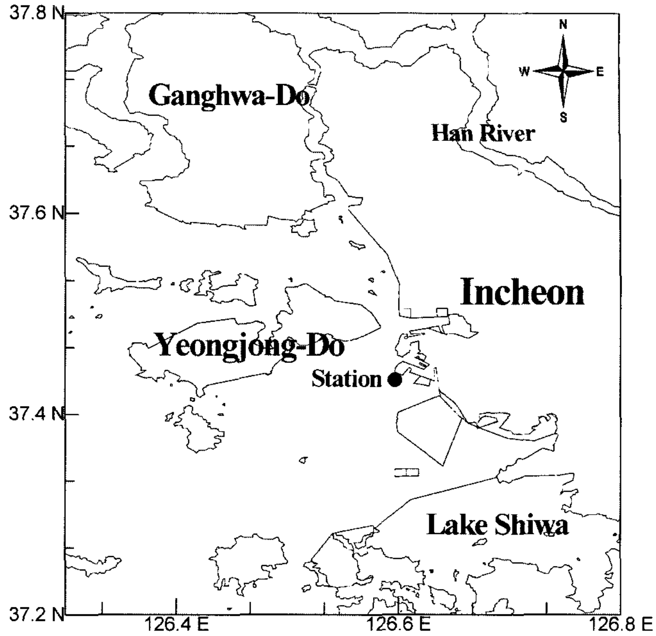

Fig. 1. Map of sampling site in Incheon coastal waters.

RESULTS

Environmental variables

During the study period, water temperature ranged from 1.5°C to 26.5°C and was lowest in February and highest in August (Fig. 2). Seasonal variations in salinity usually ranged from about 25 psu to 31 psu throughout the year. However, after heavy rain period in summer, salinity showed the lowest value (17.1 psu, July 1999). The seasonal variations in water temperature and salinity showed a similar tendency in both years (Fig. 2). Concentrations of chlorophyll *a* varied from 0.9 μg chl-*a*/*l* to 66.4 μg chl-*a*/*l* with annual means of 9.8 μg chl-*a*/*l* in 1999 and 4.8 μg chl-*a*/*l* in 2000 (Fig. 3).

Phytoplankton blooms, inferred by the variations in Chlorophyll-*a,* occurred twice in a year. In 1999, the first bloom occurred between January and late May, and the second period was between late August and mid September (Ryan-Einot-Gabriel-Welsch-multiple test, $p<0.05$). In 2000, the first bloom occurred between

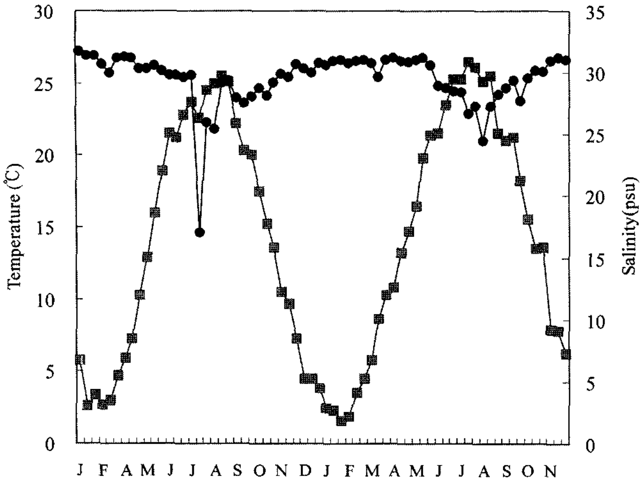

Fig. 2. Variations in seawater temperature (■) and salinity (●) from January 1999 to December 2000.

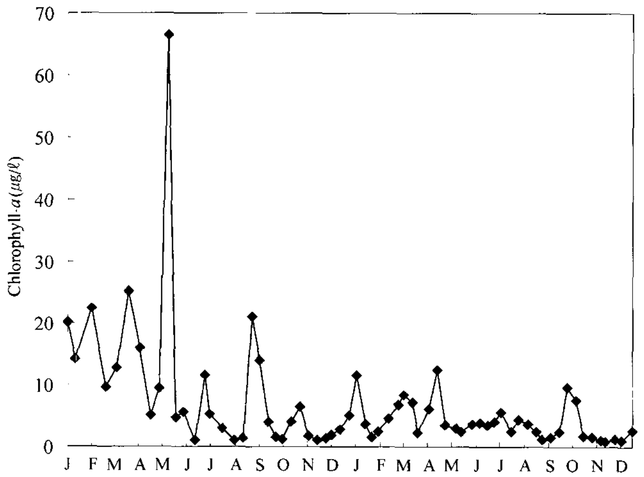

Fig. 3. Variations in chlorophyll-*a* concentrations from January 1999 to December 2000.

early January and mid April, and the second bloom occurred between late September and mid October (Ryan-Einot-Gabriel-Welsch multiple range test, $p<0.05$). Although the annual mean of chlorophyll-*a* in 1999 was two times higher than that in 2000 (t-test, $p<0.05$), seasonal tendency of the variations in chlorophyll-*a* was similar in both years. In winter-spring blooms, relative high values (>5 chl-*a*/*l*) continued during 4 to 5 months. Whereas, in summer-autumn blooms, the values were generally lower than those of winter-spring bloom and the duration was maintained for less than 30 days.

Species composition and abundance of total zooplankton community

Twenty-nine taxa of zooplankton were identified in Incheon coastal waters, which consisted of 1 dinoflagellate, 1 chaetognatha, 1 cladocera, 15 copepods, 1 appendicularia and 10 kinds of other zooplankton containing meroplankton and fish larvae (Table 1). The composition of zooplankton community in 1999 was quite similar with that in 2000. Total abundances of zooplankton were highly variable, ranging between 1,100 indiv./m^3 (Feb. 2000) and 120,400 indiv./m^3 (Oct. 1999), with annual means of 29,400 indiv./m^3 in 1999 and 13,900 indiv./m^3 in 2000 (Fig. 4). The lowest value was recorded between January and February. From March to April, the total abundances increased as water temperature rose. Between late April and late July, the total abundance sustained higher than 15,000 indiv./m^3 in both years. After August, the variations in total abundance showed an irregular pattern that intermittent peaks of abundance occurred once or twice. Relative abundance of zooplankton groups also showed a seasonal pattern. From January to April when water temperatures were below 10°C, copepods contributed more than 95% of the zooplankton community. After April, with the outburst of *Noctiluca scintillans*, relative abundance of copepods decreased. The proportion of meroplankton relatively increased during warm season. However, the values did not exceed 30% of total abundance (Fig. 5).

Table 1. List of zooplankton occurred in Incheon coastal waters during this study.

Protozoa	
Noctiluca scintillans	
Chaetognatha	
Sagitta crassa	
Cladocera	
Podon leuckarti	
Copepoda	
Calanus sinicus	***Paracalanus indicus***
Paracalanus crassirostris	*Centropages abdominalis*
Centorpages tenuiremis	*Pseudodiaptomus marinus*
Eurytemora pacifica	*Labidocera euchaeta*
Labidocera bipinnata	***Acartia hongi***
Acartia sinjiensis	*Acartia pacifica*
Tortanus spinicaudatus	*Corycaeus affinis*
Oithona similis	***Oithona davisae***
Unidentified harpacticoids	
Appendicularia	
Oikopleura spp.	
Others	
Unidentified hydrozoans	Decapod nauplii
Polychaete larvae	zoea
Mysis	Cirripedia nauplii and cyprii
Immature amphipods	Mollusca larvae
Fish eggs and larvae	Echinoderm larvae

a) Thick letters indicate the dominant species during this study.

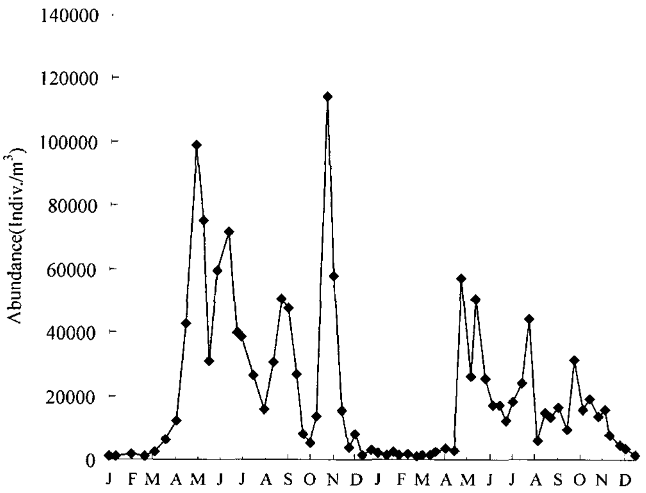

Fig. 4. Variations in total zooplankton abundance from January 1999 to December 2000.

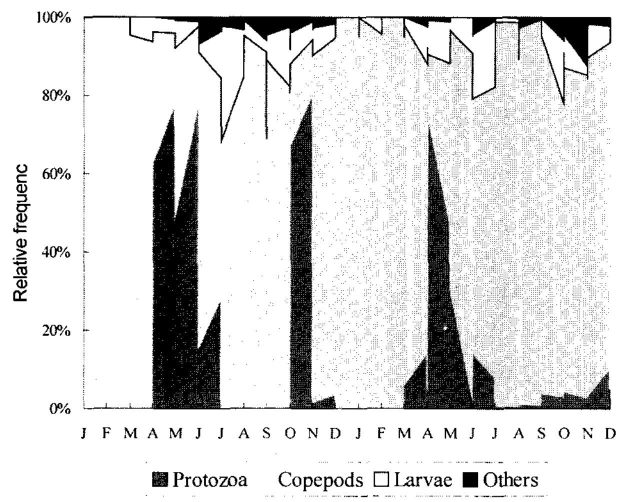

Fig. 5. Variations in relative abundance of major zooplankton taxa from January 1999 to December 2000.

Variations in abundances of dominant species

Noctiluca scintillans was the most predominant species in Incheon coastal waters throughout the year. This species occurred from April and showed a spring-autumn distribution. In spring, 2 peaks more than 30,000 indiv./m^3 appeared between May and June. Autumn peak of the cell occurred between October and November in both years (Fig. 6). Annual mean abundance were 13,300 indiv./m^3 in 1999 and 3,500 indiv./m^3 in 2000 and annual mean of relative abundance were 45% in 1999 and 25% in 2000, respectively.

Copepods constituted 46% (1999) and 65% (2000) of total zooplankton and the proportion varied seasonally, depending on the annual distribution of *Noctiluca scintillans*. Among copepods, *Acartia hongi* was dominant species, with annual mean of 6,700 indiv./m^3 (1999) and 3,400 indiv./m^3 (2000). *Acartia hongi* occupied 23% (1999) and 25% (2000) of total zooplankton and 49% (1999) and 38% (2000) of copepods, respectively. *Acartia hongi* appeared throughout the year in Incheon coastal waters and maximal peak of abundance occurred between May and July in both years. Between October and November, relative small-scale peaks occasionally appeared.

The other dominant copepods were *Oithona davisae, Paracalanus crassirostris* and *Paracalanus indicus.* Cyclopoid copepod *Oithona davisae* also occurred throughout the year, but the peaks of abundance occurred in July. Maximal peak appeared between July and October (max: 34,200 indiv./m^3, Sep. 1999) in both years. After November, the abundance of this species abruptly decreased and maintained lower density than 100 indiv./m^3 in cold season. Annual mean abundance of this species were 3,300 indiv./m^3 in 1999 and 1,800 indiv./m^3 in 2000. Annual relative abundance within total zooplankton abundance was 11% in 1999 and 13% in 2000 and those within copepods abundance were 24% in 1999 and 20% in 2000, respectively. For *Paracalanus crassirostris*, annual mean abundance was 1,500 indiv./m^3 in 1999 and 2,900 indiv./m^3 in 2000. Abundance peaks of this species occurred between July and October (max: 24,300 indiv./m^3, Aug. 1999) in both years. For *Paracalanus indicus*, annual mean abundance was 1,400 indiv./m^3 in 1999 and 600 indiv./m^3 in 2000. Though this species also occurred throughout the year, several abundance peaks happened between July and November in both years. After December, the abundance sharply decreased. *Calanus sinicus* was mainly collected from December to June (max: 900 indiv./m^3, Jun. 1999), when water temperature was lower than 20°C. Appendicularia *Oikopleura* spp. was dominant species in warm season, with annual means of 400 indiv./m^3 in 1999 and 100 indiv./m^3 in 2000. *Oikopleura* spp. was collected from July to December (max: 4,400 indiv./m^3, Oct. 1999). Among meroplanktons, cirripede nauplii were dominant taxon. Annual mean abundance was 1,100 indiv./m^3 in 1999 and 500 indiv./m^3 in 2000, respectively. Most of cirripede nauplii were collected from April to November in both years.

Principal component analysis

A principal component analysis was performed to analyze seasonal relationships among zooplankton taxa

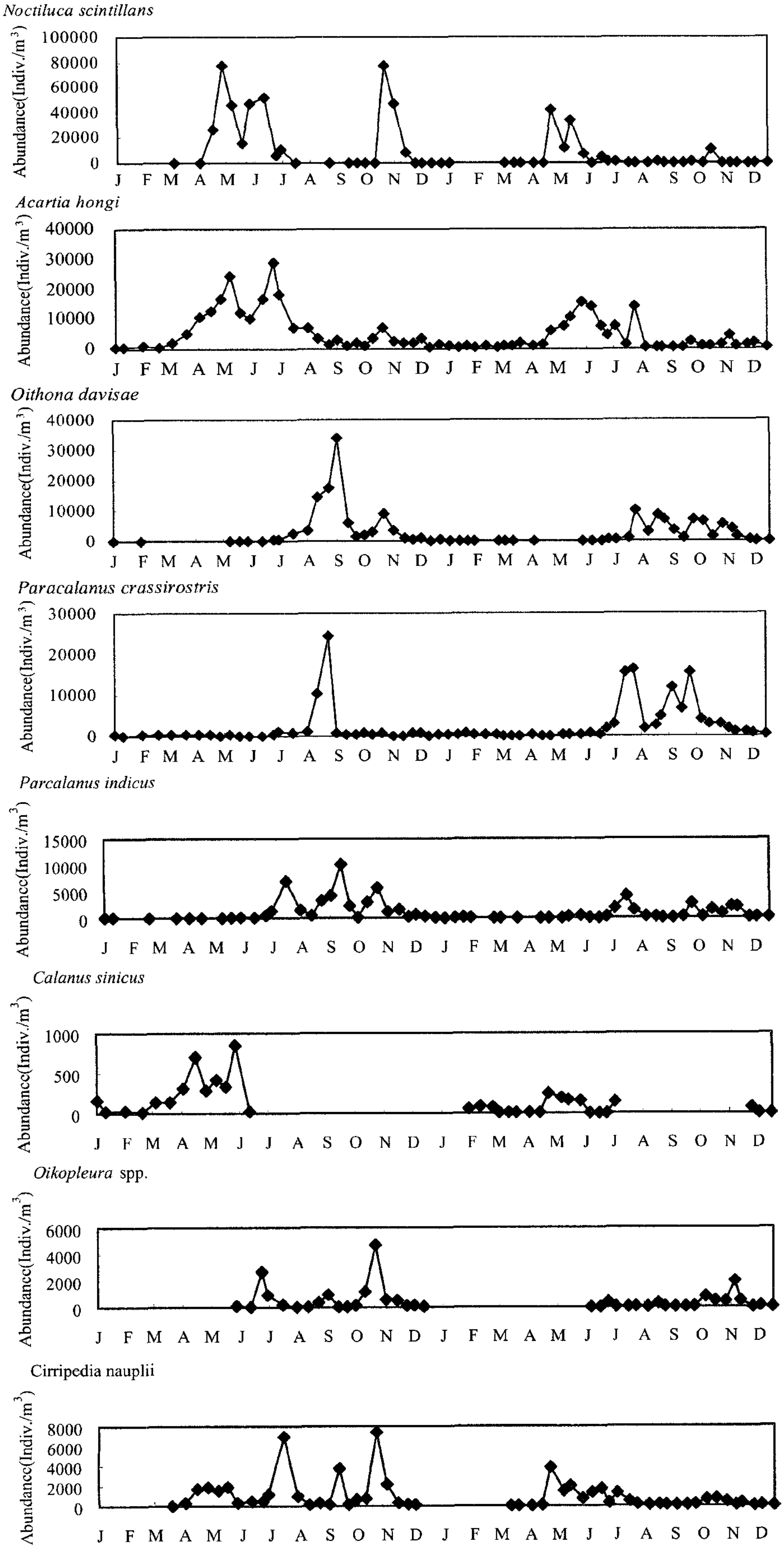

Fig. 6. Variations in abundance of dominant species from January 1999 to December 2000.

Table 2. Summary of principle component analysis based on covariance matrix of the abundance of zooplankton in Incheon coastal waters from January 1999 to December 2000.

	PC I	PC II	PC III
Percentage	57.2	20.7	7.2
Cum. Percentage	57.2	77.9	85.1
	PC I	PC II	PC III
Noctiluca scintillans	0.909	0.116	−0.317
Hydrozoans	0.048	−0.019	0.022
Sagitta crassa	−0.002	0.079	0.024
Calanus sinicus	0.046	−0.056	0.035
Paracalanus indicus	−0.014	0.352	−0.002
Paracalanus crassirostris	−0.122	0.481	0.216
Pseudodiaptomus marinus	0.028	−0.012	−0.023
Acartia hongi	0.324	0.029	0.888
Acartia pacifica	−0.008	0.055	0.065
Tortanus spinicaudatus	−0.007	0.028	−0.012
Oithona similis	0.033	−0.052	0.019
Oithona devisae	−0.111	0.731	−0.138
Corycaeus affinis	0.014	0.058	−0.100
Harpacticoids	0.005	−0.050	−0.033
Oikopleura spp.	0.035	0.157	−0.047
Polychaets larvae	0.073	0.076	−0.017
Zoea	0.028	0.003	0.102
Cirripede nauplii and cyprii	0.159	0.157	0.059
Mollusc larvae	0.018	0.064	0.039
Echinoderm larvae	−0.024	0.108	0.015
Others	0.012	0.060	0.095

a) Others indicate the sum of abundance of rare species occurred less than 30 indiv./m^3 in annual mean abundance.

and to summarize the seasonal characteristics of zooplankton community structure. Component accounted for 57.2% of the variance in the system and *Noctiuca scintillans* and *Acartia hongi* remarkably contributed to component I (Table 2). These two zooplanktons were representative dominant species in Incheon coastal waters. Component explained 20.7% of the variance and *Oithona davisae, Paracalanus crassirostris* and *Paracalanus indicus* remarkably contributed to Component II. These species were abundant in warm season. The principle component scores were schematized in the space define by componentand I and Component II (Fig. 7). The plotted scores were the monthly mean of individual scores. The upper half of a year containing December and the lower half of a year were evidently separated along an axis of component I. From December to March, as most of dominant species occurred rarely, the monthly scores in these periods converged in the negative directions on PC I and PC II. As the number of *Noctiluca scintillans* and *Acartia hongi* increased after April, the monthly scores shifted in the positive direction on PC I. The scores of August and September in both years were moved in the positive direction on PC I. The scores of July, October and November in 1999 located in the positive direction on PC I, while those in 2000 ranked in negative direction on PC I. This discrepancy was due to the annual difference of abundance of *Noctiluca scintillans* and *Acartia hongi*. The changes of direction in the locations of monthly scores were similar in both years.

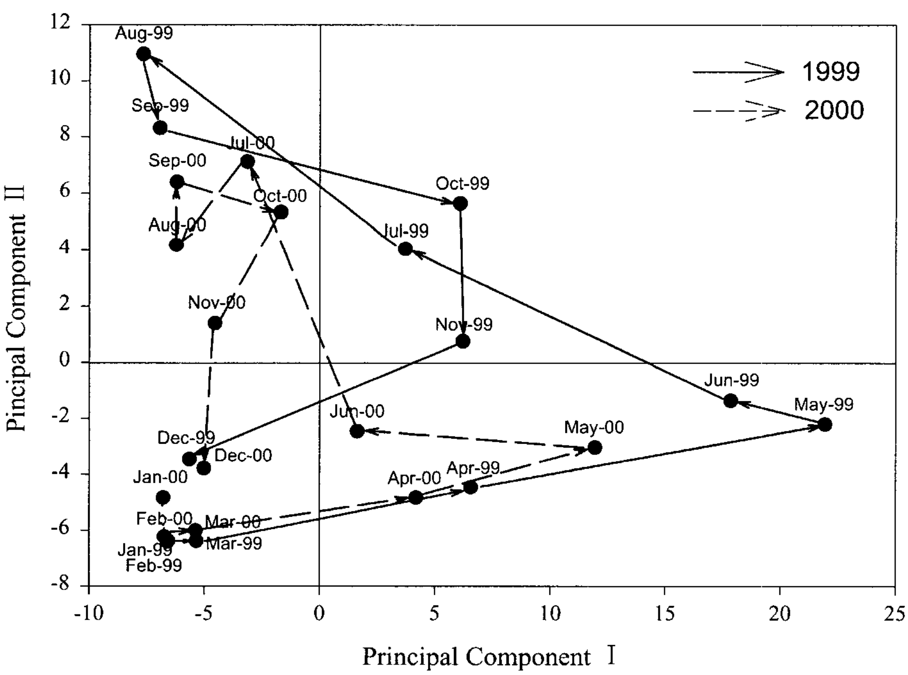

Fig. 7. Principle component ordination of 24 months using zooplankton abundance in Incheon coastal waters. The plotted scores were the monthly mean of individual scores.

DISCUSSION

Annual mean abundance of total zooplankton was 22,000 indiv./m^3 in Incheon coastal waters from January 1999 to December 2000. In comparison with published data form Yellow Sea, the abundance presented in this study was generally high (Sim *et al.*, 1988; Shim and Yun, 1990; Choi and Park, 1993; Hwang and Choi, 1993; Myung *et al.*, 1994; Yun and Choi, 1997). As the examples of similar abundance range, Shim and Choi (1996) reported that annual mean abundance of copepods was 10,700 indiv./m^3 in Incheon coastal waters (Table 3). Since zooplankton communities are composed of various size-range fauna, it is reasonable that estimated abundance of zooplankton is influenced by the mesh size of a sampling net used. Therefore, it is possible that relative high abundance in this study is attributable to the employment of fine pore-sized net. Whereas, the sampling method using fine mesh may cause a net clogging, due to high concentration of suspended particles in coastal waters, and should consider spatial patchy distribution of zooplankton (Park, 1989).

The pelagic ecosystem in Incheon coastal waters is under unstable environment due to the inputs of wastewater and eutrophicated fresh water from land (Choi and Shim, 1986a). Mass increases in abundance by a few dominant species occur sometimes under the unstable situation (Park and Huh, 1997). Dinoflagellate *Noctiluca scintillans* which was the most abundant species in this study has a cosmopolitan distribution and is known to be a origin species of red tide in eutrophicated neritic waters (Buskey, 1995). During the study period, maximal abundance of *Noctiluca scintillans* was 78,900 indiv./m^3 (Oct. 1999). Compared with previous studies, Hwang and Choi (1993) reported the mean abundance of 10,700 indiv./m^3 in central Yellow Sea and Shim (1996) reported a maximal abundance of 44,000 indiv./m^3 in Incheon coastal waters. In Seto Inland, it is reported that maximal abundance of the cell was 345,000 indiv./m^3 and the abundance peaks were associated with phytoplankton blooms (Nakamura, 1998). *Noctiluca scintillans* feeds on not only phytoplankton but also the eggs of copepods and fishes (Kimor, 1979). Okaichi and Nishio (1976) studied the chemical composition of this species, including its toxicity, and reported that the cells were enriched in ammonium. In Incheon coastal waters, the occurrence period of *Noctiluca scintillans* was from May to October, when water temperature was above 12°C. Mass increase of this species may affect the short-term variations of phytoplankton biomass and, through the predation on the eggs and copepod nauplii, influence the population dynamics of copepods.

Several *Acartia* species are known to be ubiquitous endemic copepods in coastal water (Uye, 1982; Ueda, 1991; Uriarte *et al.*, 1998; Burdloff *et al.*, 2002). Copepod *Acartia hongi* has been misidentified as *Acartia bifilosa* in the Yellow Sea, and the recent study suggested that *Acartia hongi* is a new species that could be distinguished from *Acartia bifilosa* (Soh and Suh, 2000). *Acartia hongi* is a dominant and widespread planktonic copepod in coastal regions of the Yellow Sea (Shim and Choi, 1996). Our results showed that the seasonal peaks in abundance of *Acartia hongi* were accompanied with the several phytoplankton blooms. The abundance of this species increased from March in both years. Since winter-spring phytoplankton bloom terminated in April, the peaks of *Acartia hongi* occurred between May and June in both years. These variation patterns could be observed similarly in autumn. Cross-correlation analysis between the abundance of zooplankton and chlo-

Table 3. Published data of zooplankton abundance in Yellow Sea.

Area	Mesh (μm)	Abundance (indiv./m^3)	Authors
Mid-eastern Yellow Sea	250	2,527 (mean)	Sim *et al.* (1988)
Mid-eastern Yellow Sea	300	437–44,233	Hwang and Choi (1993)
Chonsu Bay	200	1,773–35,331	Shim amd Yun (1990)
Asan Bay	333	6,000 *(max.)	Choi and Park (1993)
Asan bay	333	876 (mean)	Myung et al. (1994)
Incheon dock	70	990,000 (max.)	Kim and Lee (1994)
Kyeonggi Bay	100	10,727 **(mean)	Shim and Choi (1996)
Kyeonggi Bay	Water sample	99,288 **(mean)	Shim and Choi (1996)
Kyeonggi Bay	200	3,369 (mean)	Yun and Choi (1997)
Kyeonggi Bay	60	21,957 (mean)	This study

a)*The value was inferred from figure and abundance of *Noctiluca scintillans* was excluded.
b)**The values were the abundance of copepods.

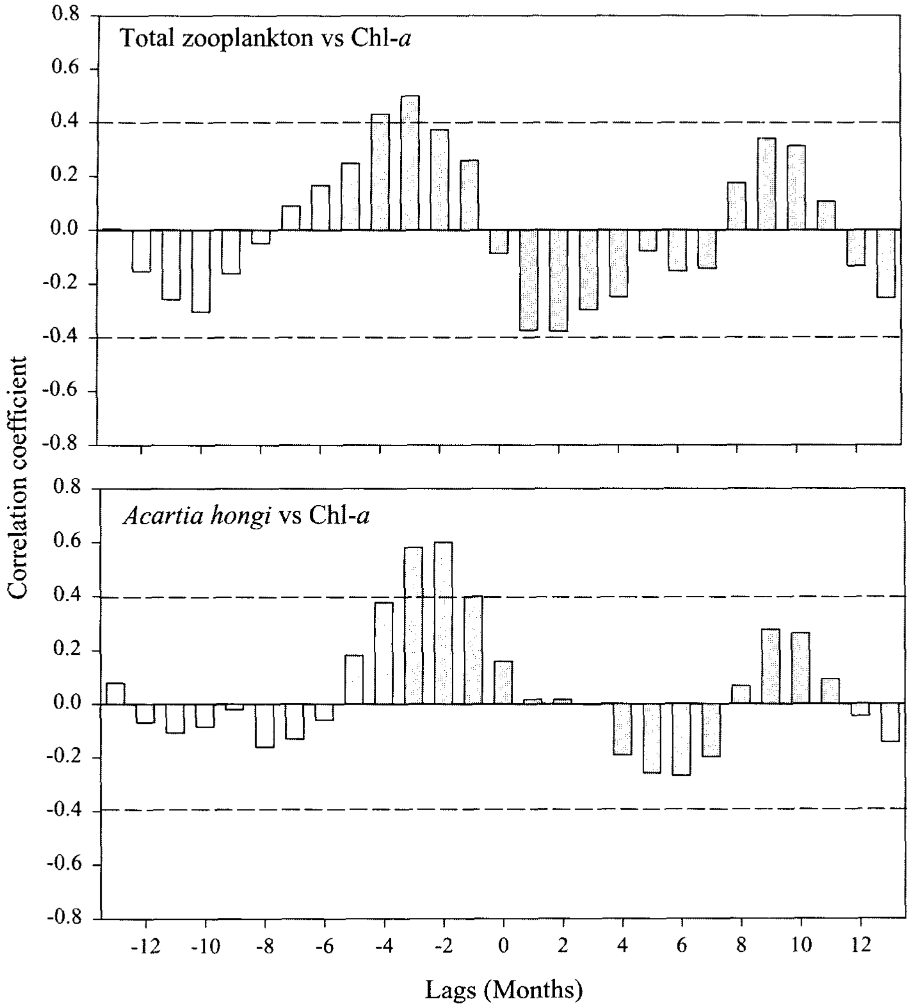

Fig. 8. Cross-correlation of the monthly mean abundance of total zooplankton and copepod *Acartia hongi* versus the monthly mean of chlorophyll-*a*. Data were transformed into log-form before the analysis. Dashed lines in cross-correlation plots indicate two standard errors.

rophyll-*a* was carried out to identify a delay in seasonal abundance patterns (Fig. 7). Cross-correlation between the abundance of total zooplankton and chlorophyll-*a* revealed a significant 3–4 month delay, and the abundance of *Acartia hongi* versus chlorophyll-*a* also showed a significant 2–3 month delay. These results indicated that the temporal variations in abundance of zooplankton were closely related with those of phytoplankton in Incheon coastal waters. Especially, we considered that the seasonal variations in abundance of *Acartia hongi* occurring seasonal peaks in spring and autumn were affected the quantitative intensity and the maintenance duration of seasonal phytoplankton blooms that had occurred ahead of the peaks. Weight-specific egg production rates of *Acartia hongi*, measured simultaneously in this study, showed a significant positive correlation with the concentrations of >20 μm chlorophyll-*a* when water temperature was higher than 10°C (unpublished data). The reproductive rates were high when food resources were plentiful, suggesting that food availability is important in regulating the abundance of copepods in Incheon coastal waters.

It was referred in previous studies that *Acartia pacifica, Paracalanus indicus, Corycaeus affinis* and meroplankton were dominant during warm season in the coastal waters of Yellow Sea (Sim *et al.*, 1988; Choi and Park, 1993; Hwang and Choi, 1993; Myung *et al.*, 1994; Yun and Choi, 1997). Although the species mentioned above also occurred frequently in this waters during the warm season, the summer dominant species were small copepods *Oithona davisae* and *Paracalanus crassirostris* of which body length are less than 1 mm. In the estuaries near Beaufort in Atlantic Ocean, seasonal succession of copepod community varied from a spring assemblages dominates by the medium-sized copepod *Acartia tonsa* to a summer-autumn assemblages dominated by the small-sized copepods *Paracalanus crasisrostris* and *Oithona colcarva* (Fulton, 1984). Cyclopoid copepod *Oithona davisae* occurred abundantly in the study waters during warm season. The copepod was known to be a dominant zooplankton in temperate eutrophic coastal waters (Ueda, 1991; Uye and Sano, 1995). In domestic waters, Kim and Lee (1994) reported that this species occurred abundantly in Incheon dock during summer. In Fukuyama Bay, it was reported that the secondary production of *Oithona davisae* was 650 mg C/m^3/yr, 94% of which was attained between June and October, and contributed 26% of the annual copepod production (Uye and Sano, 1998). In North Sea, the contribution of *Oithona* spp. ranged from 13% to 40% of total copepod production (Nielsen and Sabatini, 1996). Our result showed that the abundance of *Oithona davisae* and *Paracalanus crassirostris* contributed 51% of copepod abundance from July to September in both years.

The seasonal succession of zooplankton community might be sometimes influenced by the variations in species composition and biomass of phytoplankton (Calbet *et al.*, 2001). In Peconic Bay located in northwestern of Atlantic Ocean, Turner *et al.* (1983) reported that, during the cold season, the plankton community was mainly composed of net phytoplankton such as diatoms and long chains of nano plankton and large or medium-sized copepods, however, during the warm season, the community was dominated by nano phytoplankton and small zooplankton. It was reported that most of annual phytoplankton blooms was produced by diatoms in Kyeonggi Bay (Choi and Shim, 1986c). However, during this study period, the seasonal variations in size-fractionate chlorophyll *a* showed that nano chlorophyll-*a* (<20 μm) contributed 62% of total chlorophyll-*a* from July to October in both years (Youn and Choi, unpublished data). It is uncertain whether these small copepods directly feed on nano phytoplankton or utilize other microbes derived from the increase of nano phytoplankton. Uchima (1988) suggested that main food items of *Oithona davisae* were flagellates, ciliates and nauplii of small copepods. Therefore, further studies on the succession mechanism associated with food availability need to be conducted in Kyeonggi Bay.

Principal component analysis suggested that the formation of zooplankton community in Incheon coastal waters was affected by a few dominant species. Seasonal succession of zooplankton community could be recognized into three patterns; winter, spring and summer-autumn. Though the annual abundance of zooplankton differed considerably between 1999 and 2000, the process of seasonal succession of zooplankton community was repeated in both years. This indicated that the seasonal variations in water temperature were concomitant with the seasonal succession of zooplankton community in Incheon coastal waters.

Annual mean abundances of total zooplankton between 1999 and 2000 differed significantly (t-test, $p<0.05$). Previous several studies have suggested that the main affecting factors of growth and production of zooplankton are seawater temperature (Uye, 1982; Huntley and Lopez, 1992) and food availability (Durbin *et al.*, 1983; Kiørboe and Nielsen, 1994; Schmidt *et al.*, 1998; Halsbund and Hirche, 2001). Long-term variations in zooplankton biomass are generally influenced by the climate variability (Nakata *et al.*, 2001). In the East Sea of Korea, zooplankton biomass showed an increasing trend since late 1980's, due to a warm regime shift (Kang *et al.*, 2001). The water temperature in 1999 was not significantly different from that in 2000, while annual mean of chlorophyll-*a* in 1999 was significantly 2-times higher than in 2000 (t-test, $p<0.05$). Calbet and Agusti (1999) suggested that the abundance of zooplankton was determined mainly by the standing stock of phytoplankton. Our results also showed that the abundance of zooplankton in Incheon coastal waters directly affected by the phytoplankton biomass of 2–4 months before.

The 2-years time series data on the seasonal changes in zooplankton community in Incheon coastal waters could clarify the repeated and predictable process of seasonal succession of zooplankton community and the relationship between zooplankton and phytoplankton involving time lag. Consequently, we suggest that the seasonal succession of zooplankton community is related to the seasonal variations in water temperature and the seasonal variations in zooplankton abundance appear to depend primarily on the phytoplankton biomass in Incheon coastal waters.

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REFERENCES

Burdloff, D., S. Gasparini, F. Villate, I. Uriarte, U. Cotano, B. Sautour, and H. Etcheber, 2002. Egg production of the copepod *Acartia bifilosa* in two contrasting European estuaries in relation to seaton composition. *J. Exp. Mar. Biol. Ecol.*, **274**: 1–17.

Buskey, E., 1995. Growth and bioluminescence of *Noctiluca scintillans* on varying algal diets. *J. Plankton Res.*, **17**: 29–40.

Calbet, A. and S. Agusti, 1999. Latitudinal changes of copepod egg production rates in Atlantic waters: temperature and food availability as the main driving factors. *Mar. Ecol. Prog. Ser.*, **181**: 155–162.

Calbet, A., S. Garrido, E, Saiz, M. Alcarez and C.M. Duarte, 2001. Annual zooplankton succession in coastal NW Mediterranean waters: the importance of the smaller size fractions. *J. Plankton Res.*, **23**: 319–331.

Choi, K.H. and C. Park, 1993. Seasonal fluctuation of zooplankton community in Asan Bay, Korea. *Bull. Korean Fish. Soc.*, **26**: 424–437.

Choi, J.K. and J.H. Shim, 1986a. The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea II. Environmental characteristics. *J. Korean Soc. Oceanogr.*, **21**: 56–71.

Choi, J.K. and J.H. Shim, 1986b. The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea I. Light intensity, transparency, suspended substances. *J. Korean Soc. Oceanogr.*, **21**: 101–109.

Choi, J.K. and J.H. Shim, 1986c. The ecological study of phytoplankton in Kyeonggi Bay, Yellow Sea III. Phytoplankton composition, standing stock, tychopelagic plankton. *J. Korean Soc. Oceanogr.*, **21**: 156–170.

Chung, K.H. and Y.C. Park, 1988. Primary production and nitrogenous regeneration by zooplankton in the Kyunggi Bay, Yellow Sea. *J. Korean Soc. Oceanogr.*, **23**: 194–206 (in Korean).

Colebrook, J.M., 1979. Continuous plankton records: Seasonal cycles of phytoplankron, copepods in the North Atlantic Ocean and the North Sea, *Mar. Biol.*, **51**: 23–32.

Durbin. E.G., A.G. Durbin, T.J. Smayda and P.G. Verity, 1983. Food limitation of production by adult *Acartia tonsa* in Narragansett Bay, Rhode Island. *Limnol. Oceanogr.*, **28**: 1199–1213.

Fulton, R.S. III, 1984. Predation, production and the organization of an estuarine copepod community. *J. Plankton Res.*, **6**: 399–415.

Halsbund, C. and H.-J. Hirche, 2001. The reproductive cycles of dominant calanoid copepods in the North Sea. *Mar. Ecol. Prog. Ser.*, **209**: 219–229.

Hwang, H.J. and J.K. Choi, 1993. Seasonal characteristics of zooplankton community in the mid-eastern part of Yellow Sea. *J. Korean Soc. Oceanogr.*, **28**: 24–34 (in Korean).

Huntley, M.E. and M.D.G. Lopez, 1992. Temperature-dependent production of marine copepods: a global synthesis. *Am. Mat.*, **140**: 201–242.

Kang, Y.S., J.Y. Kim, H.G. Kim and J.H. Park, 2001. Long-term trend in zooplankton and its relationship with squid, *Todarodes pacificus*, in the East Sea of Korea. In: Proceedings of the Korea-Japan joint GLOBEC symposium 『Long-term variations in the Northwestern Pacific ecosystems』, edited by Sugimoto, T., S. Kim and M. Terazaki, Japan-GLOBEC Subcommittee *et al.*, pp. 103–111.

Kim, S.W. and J.H. Lee, 1994. Seasonal distribution of zooplankton communities in Inchon dock, an artificially closed marine embayment facing the Yellow Sea, western Korea. *J. Korean Soc. Oceanogr.*, **29**: 376–382.

Kimmerer, W.J., 1993. Distribution patterns of zooplankton in Tomales Bay, California. *Estuaries*, **16**: 254–272.

Kimor, B., 1979. Predation by *Noctiluca miliaris* Souriray on *Acartia tonsa* Dana eggs in the inshore waters of southern California. *Limnol. Oceanogr.*, **25**: 568–572.

Kiørboe, T. and T.G. Nielsen, 1994. Regulation of zooplankton biomass and production in a temperate, coastal ecosystem. I. Copepods. *Limnol. Oceanogr.*, **39**: 493–507.

Myung, C.S., 1992. An ecological study on zooplankton community in brackish water, Han River Estuary. M.S. thesis, Inha University, 88 pp. (in Korean).

Myung, C.S., J.M. Yoo and W.S. Kim, 1994. Distribution of zooplankton in Asan Bay, Korea. *J. Korean Soc. Oceanogr.*, **29**: 366–375 (in Korean).

Nakamura, Y., 1998. Biomass, feeding and production of *Noctiluca scintillans* in the Seto Inland Sea, Japan. *J. Plankton Res.*, **20**: 2213–2222.

Nakata, K., S. Koyama and Y. Matsukawa, 2001. Interannual variation in spring biomass and gut content composition of copepods in the Kuroshio current, 1971-80. *Fish. Oceanogr.*, **10**: 329–342.

Nielsen, T.G. and M. Sabatini, 1996. Role of cyclopoid copepods *Oithona* spp. in North Sea plankton communities. *Mar. Ecol. Prog. Ser.*, **139**: 79–93.

Okaichi, T. and S. Nishio, 1976. Identification of ammonia as the toxic principle of red tide of *Noctiluca miliaris*. *Bull. Plankton Soc. Japan*, **23**: 75–80.

Omori, M. and T. Ikeda, 1984. Methods in marine zooplankton ecology. Wiley-Internscience, New York, 322 pp.

Park, C., 1989. Zooplankton sample variability in the coastal area: the necessity for the replicated and time dependent sampling. *J. Korean Soc. Oceanogr.*, **24**: 165–171 (in Korean).

Park, C. and S.H. Huh, 1997. Ecological stability of the Shihwa Lake evaluated by zooplankton distribution in the Lake Shihwa and adjacent coastal area. 「The Sea」 *J. Korean Soc. Oceanogr.*, **2**: 87–91 (in Korean).

Parsons. T. R., Y. Maita and C.M. Lalli, 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press, Oxford, 173 pp.

Schmidt, K., P. Kahler and B. von Bodungen. 1998. Copepod egg production in the Pomeranian Bay (Southern Baltic Sea) as a function of phytoplankton abundance and taxonomic composition. *Mar. Ecol. Prog. Ser.*, **174**: 183–195.

Shim, J.H. and K.H. Yun, 1990. Seasonal variation and production of zooplankton in Chonsu Bay, Korea. *J. Korean Soc. Oceanogr.*, **25**: 229–239.

Shim, M.B., 1996. A study on the *Acartia bifilosa* Giesbrecht (Copepods:Acartiidae) in the coastal area of Inchon, Korea. Ph. D. Thesis, Inha University, Inchon, 116 pp.

Shim, M.B. and J.K. Choi, 1996. A study on the seasonal succession of copepod community in Kyeonggi Bay, Yellow Sea through the short interval surveys. *The Yellow Sea*, **2**: 65–73.

Sim, M.B., J.K. Choi and D.Y. Kim, 1988. The distribution of zooplankton in the mid-eastern part of the Yellow Sea. *Yellow Sea Res.*, **1**: 1–10 (in Korean).

Soh, H.Y. and H.L. Suh, 2000. A new species of *Acartia* (Copepoda, Calanoida) from the Yellow Sea. *J. Plankton Res.*, **22**: 321–337.

Turner, J.T., S.F. Bruno, R.J. Larson, R.D. Staker and G.M. Sharma, 1983. Seasonality of plankton assemblages in a temperate estuary. *Mar. Ecol.*, **4**: 81–99.

Uchima, M., 1988. Gut content analysis of neritic copepods *Acartia omorii* and *Oithona davisae* by a new method. *Mar. Ecol. Prog. Ser.*, **48**: 93–97.

Ueda, H. 1991. Horizontal distributions of planktonic copepods in inlet waters. In: Proceedings of the fourth international conference on Copepoda, edited by Uye, S.S. Nishida and J.S. Ho, Planktonic Society of Japan, Hiroshima, pp. 143–160.

Uriarte, I., U. Cotano and F. Villate, 1998. Egg production of

Acartia bifilosa in the small temperate estuary of Mundaka, Spain, in relation to environmental variables and population development. *Mar. Ecol. Prog. Ser.*, **166**: 197–205.

Uye, S., 1982. Population dynamics and production of *Acartia clausi* Giesbrecht (Copepoda:Calanoida) in inlet waters. *J. Exp. Mar. Biol. Ecol.*, **57**: 55–83.

Uye, S. and K. Sano, 1995. Seasonal reproductive biology of the small cyclopoid copepod *Oithona davisae* in a temperate eutrophic inlet. *Mar. Ecol. Prog. Ser.*, **118**: 121–128.

Uye, S. and K. Sano, 1998. Seasonal variations in biomass, growth rate and production rate of the small cyclopoid copepod *Oithona davisae* in a temperate eutrophic inlet. *Mar. Ecol. Prog. Ser.*, **163**: 37–44.

Yi, S.U., 1972. On the tides, tidal currents and tidal prism at Incheon Harbour. *J. Korean Soc. Oceanogr.*, **7**: 86–97.

Yun, S.H. and J.K. Choi, 1997. A study on the seasonal distribution of zooplankton community in Inchon coastal waters, Korea. *Yellow Sea Res.*, **7**: 91–104 (in Korean).

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