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Seasonal Distribution of Zooplankton Communities in Inchon Dock, an Artificially Closed Marine Embayment Facing the Yellow Sea, Western Korea

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인천항 선거내 동물플랑크톤 군집의 계절 변동

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Seasonal distribution of zooplankton community in Inchon Dock, an artificially closed marine embayment has been studied. Samples were collected monthly during the period from December 1989 to December 1991 at four stations in the dock and compared with that at a single station in neighbouring waters of the Yellow Sea. Copepods dominated both in- and outside of the dock all the year round, except in late autumn and early winter when protozoans outnumbered. Dominant species were *Oithona davisae, Acartia bifilosa, Paracalanus crassirostris, Noctiluca scintillans* and *Tintinnopsis tubulosa*. A sharp decline in the abundance was observed in summer 1990 in the dock apparently due to oxygen deficiency (anoxic condition). Although no distinct difference in the abundance of zooplankton was observed between populations in- and outside of the dock except in summer 1990, waters out of the dock showed to have a prosperity in species number throughout the year. Moreover, four species of copepods, *Centropages abdominalis, Pseudodiaptomus marinus, Tortanus forcipatus* and *T. spinicaudatus* occurred solely at the outside of the dock.

인공적으로 폐쇄된 생태계인 인천항 선거내에서 동물플랑크톤 군집의 계절적 출현을 조사하기 위하여 1989년 12월부터 1991년 12월까지 매월 5개 정점(선거내 4개 정점 및 선거밖 1개 정점)에서 정량 채집을 실시하였다. 늦은 가을과 이른 겨울에 원생동물이 대량 출현한 것을 제외하면 요각류가 선거 안팎 모두에서 우점하고 있었다. 우점종은 *Oithona davisae, Acartia bifilosa, Paracalanus crassirostris, Noctiluca scintillans, Tintinnopsis tubulosa* 등이었는데 1990년 여름에는 산소부족으로 인하여 선거내에서 *A. bifilosa*를 제외하고는 모두 소멸하였다. 1990년 여름을 제외하고는 선거 안팎의 동물플랑크톤 출현량 차이가 뚜렸하지 않았으나 선거 밖에서 연중 출현 종수가 많았는데 특히 *Centropages abdominalis, Pseudodiaptomus marinus, Tortanus forcipatus, T. spinicaudatus* 등 4종의 요각류는 선거 밖에서만 출현하였다.

INTRODUCTION

Zooplankters play an important role in the trophodynamics of the marine ecosystem as secondary producers. Ecological aspects of zooplankton community in the particular waters have been studied in open oceans as well as in coatal waters. Moreover, a number of investigation have been carried out to clarify the ecological role of zooplankters on the production of enclosed seas, such as the Inland Sea of Japan (Hirota. 1968). However, knowledge on zooplankton which live in arti-

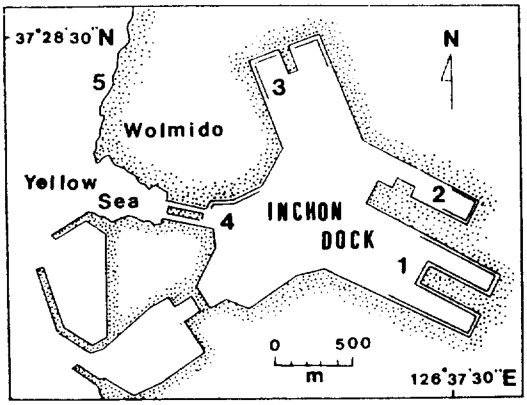

Fig. 1. A map showing the study area and five sampling stations.

ficially closed saline waters is very limited (Hada *et al.*, 1986), probably due to rare occurrence and unique hydrography of an artificial basin.

The Inchon Dock was reconstructed with enlargement in 1974 and had an unique feature with its inner waters isolated from the outer Yellow Sea. Then it formed an artificially closed marine ecosystem. It has been investigated the annual and seasonal dynamics of the benthic macroalgal flora (Yoo, 1990) and planktonic diatoms (Lee and Byun, 1991) in the dock. However, little is known on the ecology of zooplankton community in the dock.

The objective of the present study is to clarify the seasonal distribution of zooplankton community in the Inchon Dock as part of a three year study: "Ecological studies on the biotic communities and the energy flow in the Inchon Dock ecosystem, 1989-1992". Spatial and temporal variations between the in- anu outside waters of the dock are also presented.

MATERIALS AND METHODS

Inchon Dock (Fig. 1) is located in Kyeonggi Bay, western Korea, where its opening faces the eastern coast of the Yellow Sea. This harbor is located 32km west to Seoul. Since the enterance into Inchon Harbor had been hindered by its large tidal range exceeding 10m and shallowness, an opening-closing dock was constructed in 1918. Stn 2 is located at this earlier dock. With the increase of foreign trade in Korea, the dock was enlarged in 1974. An average depth was 10m just after its construction, but it became to be shallow gradually last two decades, due to sedimentation. The dock measured 5-6m in depth at present.

Among five sampling stations, Stns 1-4 are located within the dock, which can be referred as an artificially closed marine ecosystem. Stn 5 is located at the outside the dock in the eastern coastal waters of the Yellow Sea. Stn 1 is off the wharf for container ships, where oil film always covered. At Stn 2, water exchange maybe minimized due to the bottle-neck shaped aperture of the area. The elevators for grain unshipment are situated near Stn 3, where floating scraps were observed on the water at every sampling time. Stn 4 is located just inside the two lock gates: as a result, circulation with outer waters of the dock maybe limited in the nighttime. Stn 5 is located near the Wolmi Port.

According to Seung (1990), little influence of ocean currents, i.e. Kuroshio Current, appears in the Yellow Sea. The coastal water of the Yellow Sea is characterized by its low salinity (31.0-33.0‰), low transparency (3-5 m) and great seasonal fluctuation in surface water temperature (2-8℃ in winter, 24-29℃ in summer) (Yoo, 1990). Hydrographical parameters were measured both from surface and bottom simutaneously with zooplankton sampling. In Stn 5, only surface temperature was measured. Water temperature and salinity were recorded with a portable S-C-T meter (YSI, Model 33). Dissolved oxgen (DO) was measured with a portable DO meter (YSI, Model 84). Quantitative zooplankton samples were collected monthly during the period from December 1989 to December 1990 at five stations using a conical plankton net (mouth diameter 30 cm, mesh opening 0.07 mm) equipped with a flowmeter. The net was hauled vertically from near bottom to surface in the dock and obliquely at Stn 5. With three times of hauls, the volume of waters strained through the net was more than 1 m^3 for each sample (cf. Park *et al.*, 1989). Samples were immediately preserved in 4% formaldehyde in seawater, buffered with borax.

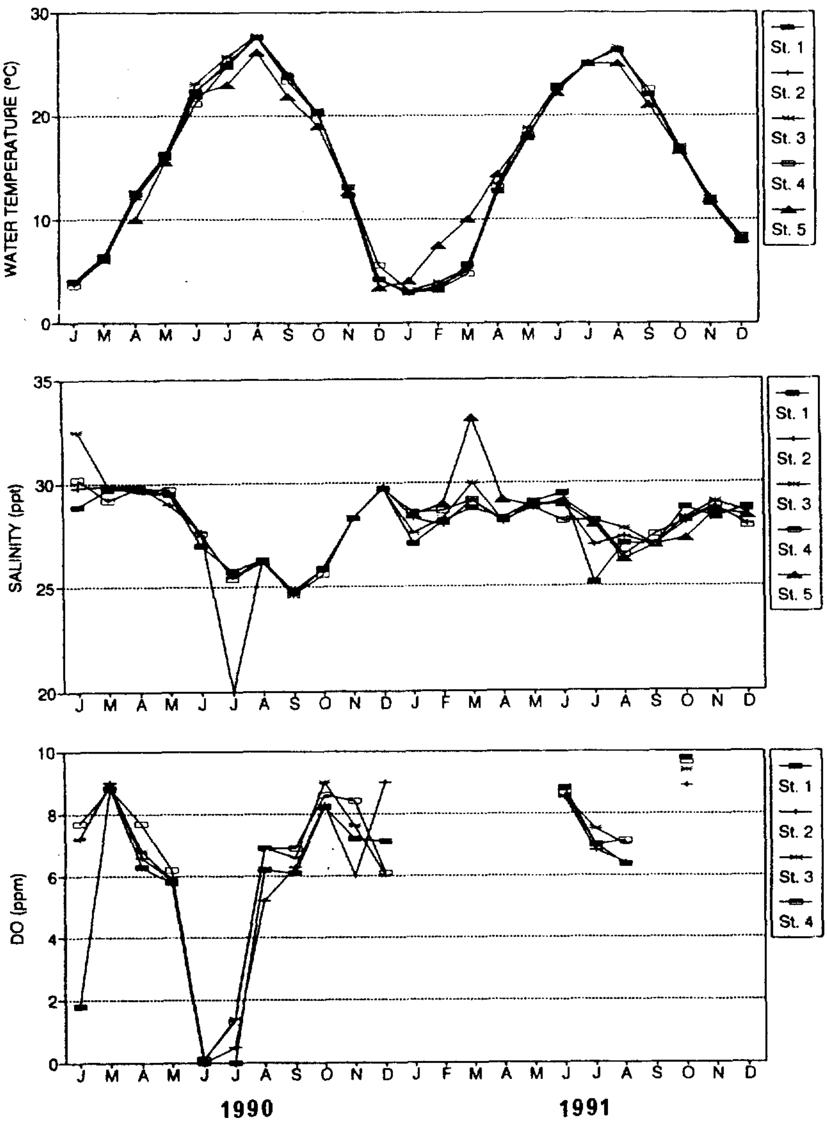

Fig. 2. Seasonal variations in temperature, salinity and dissolved oxygen in 1990-1991 at five stations in Inchon Dock.

Each sample was examined under a dissecting microscope and the identification of copepods to species was mainly done with higher magnification. The number of each species was converted to number per cubic meter of water.

RESULTS

Water temperatures at insde of the Inchon Dock fluctuated greatly between 2.6℃ in January and 27.7℃ in August. Due to its shallow depth, temperature differences between the surface and bottom were hardly observed, except for Stn 1 where the bottom temperature was slightly lower in spring. This agrees well with the previous report for 1978-1979 by Yoo (1990). Temperature fluctuation of dock water was generally more intensive than that of outside waters at Stn 5, ranging from 3.4 to 26.1℃. Spatial variation in temperature, however, was hardly observed among four stations in the

Table 1. List of zooplankton occurred in 1989-1991 in Inchon Dock, and neighbouring waters of the Yellow Sea

PROTOZOANS	
Tintinnopsis tubulosa	***Noctiluca scintillans***
T. uruguayensis	*Globigerina* sp.
COPEPODS	
Calanus sinicus	*Clausocalanus furcatus*
Paracalanus crassirostris	*Centropages abdominalis*
P. indicus	*Pseudodiaptomus marinus*
Acartia bifilosa	***Eurytemora pacifica***
A. hudsonica	*Labidocera euchaeta*
A. omorii	*Tortanus forcipatus*
A. pacifica	*T. spinicaudatus*
Oithona davisae	*Oncaea venusta*
O. similis	*Corycaeus affinis*
Microsetella norvegica	*C. andrewsi*
Euterpina acutifrons	*Tisbe* sp.
unidentified copepodid	unidentified copepod nauplius
OTHERS	
Trichocerca marina	***Oikopluera dioika***
Podon polyphemoides	*Sagitta crassa*
Polychaeta larvae	Pluteus larvae
Barnacle cyprid	Decapoda zoea
Fish egg & larvae	unidentified Hydromedusa
unidentified Nematoda	unidentified Amphipoda

*Thick letter indicates the species occurred dominantly during the study.

dock (Fig. 2).

The surface salinity was generally high in cold season and low in warm season ranging from 24.03‰ in July to 32.80‰ in January. Except in January 1990, salinity did not exceed 30‰ during the study period. According to Yoo (1990), surface salinity at the outside of the dock ranged from 30.39 to 34.74‰ in 1978-1979. Her data also showed a similar pattern of variation in salinity to the present study. She reported that the salinity was high in winter and spring and low in summer and autumn. Salinty in the dock can be dropped sharply by heavy rainfalls in the summer, but such a decline was not observed in the outside. Lower salinity inside the dock than outside all the year round suggests that there was freshwater input in the dock.

DO ranged from 4.9 to 9.4 mg·l^{-1} in the dock except for June 1990 when anoxic condition occurred at Stns 1 and 2. These values were quite low when compared with those obtained by Yoo (1990), viz, the minimum DO value of 2.5 mg·l^{-1}

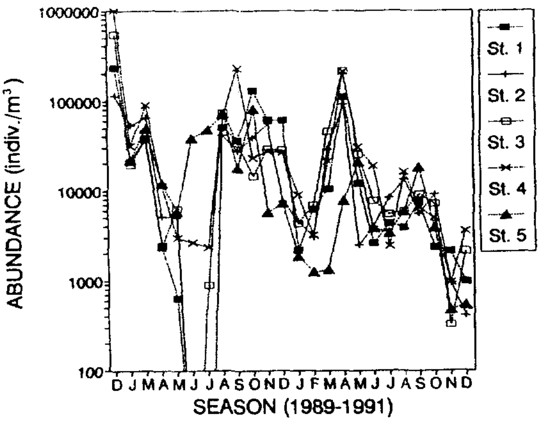

Fig. 3. Seasonal fluctuation in the abundance of zooplankton in 1989-1991 at five stations in Inchon Dock.

in August and the maximum of 16.1 mg·l^{-1} in March 1979. Particularly in summer 1990, oxygen deficiency occurred commonly in the dock except for Stn 4.

During the period of investigation, a total of 30 species of zooplankton was identified (Table 1). Copepods were the largest constituent in species number (21 species). The rest consisted of three species of protozoans, one rotifer, one chaetognath, one cladoceran and one appendicularian. Both one species of protozoan and copepod were identified to genus level. Except for these 30 species identified, 10 kinds of planktonic animals are grouped into hydromedusae, nematods and copepodids, etc.

Fig. 3 shows the seasonal change in the zooplankton abundance at five stations. Copepods dominated in the study area throughout the year (Fig. 4). Sporadic prevalence of protozoans was also observed. For example, a dense population (775,000 indiv.m^{-3}) of a single species of protozoan *Tintinnopsis tubulosa* was found at Stn 4. Then a total abundance at Stn 4 was 990,000 indiv.m^{-3} in December 1989. In 1990, abundances lower than 130,000 indiv.m^{-3} were observed all the year round, except for September at Stn 4, when and where, 226,000 indiv.m^{-3} was recorded by the prevalence of *Oithona davisae* (205,000 indiv.m^{-3}) including naupliar, copepodid and adult stages.

In June 1990, Stn 4 was the only station where

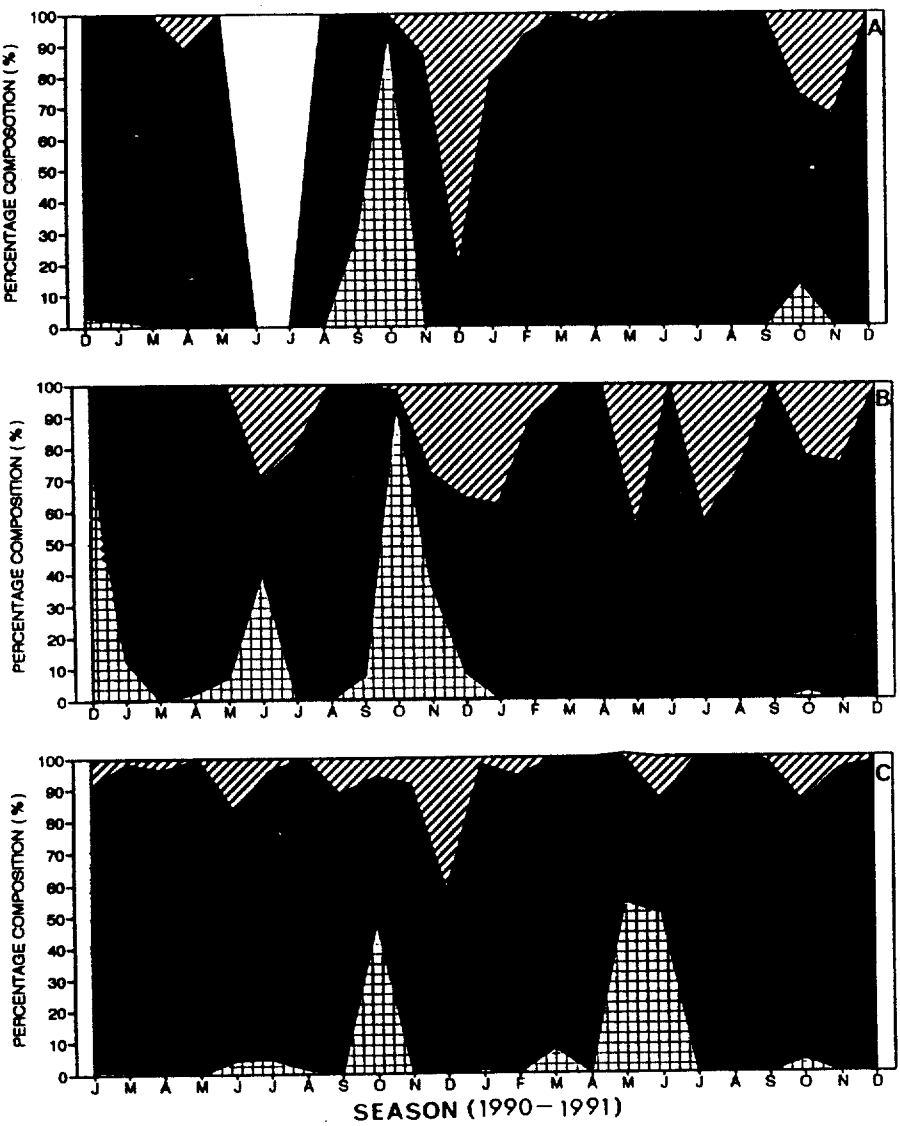

Fig. 4. Seasonal variations in percentage composition of major groups of zooplankton. A: Stn 1, B: Stn 4, C: Stn 5. Cross area: protozoans, solid area: copepods, copepodids and copepod nauplii, hached area: other zooplankters.

zooplankton was distributed among four stations in the dock. At the same time, the increase in zooplankton abundance was observed at the outside of the dock, coastal waters of the Yellow Sea. In the dock, *Acartia bifilosa* was the only species identified to species level. Except this month, *Paracalanus crassirostris* was revealed to be the sole species which distributed in the study area all the year round. In contrast, such a drastic disappearence was not observed in 1991: *A. bifilosa* and *P. crassirostris* occurred abundantly in summer season.

Fig. 4 shows seasonal variations of the percentage composition of major groups both in- and outside of the dock. Copepods consisted of more than 70% of total zooplankton abundance throughout the year in the study area, except when protozoans or Polychaeta larvae prevailed. In October 1990, *Noctiluca scintillans* consisted of 80% of zoop-

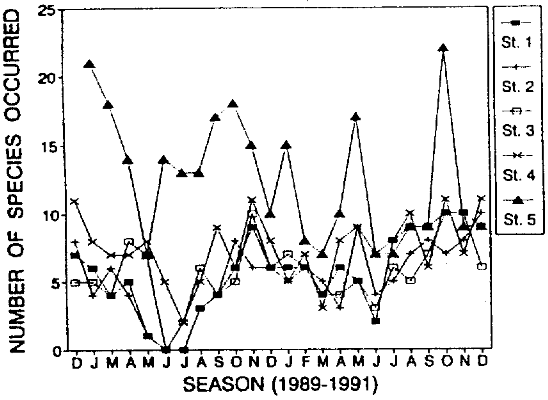

Fig. 5. Seasonal variations in the number of species occurred in 1989-1991 at five stations in Inchon Dock.

lankton community in the dock, while 50% in coastal waters of the Yellow Sea. Despite sporadic prevalence of protozoans or Polychaeta larvae, copepods were the most important member for determining zooplankton abundnace in the area. Four species of copepods, *Centropages abdominalis*, *Pseudodiaptomus marinus*, *Tortanus forcipatus* and *T. spinicaudatus* were distributed only in coastal waters and could not penetrate into the dock.

Fig. 5 shows the spatial and temporal variations in the number of species occurred in the study area. In January 1990, 23 taxa were distributed at Stn 5, while less than 8 taxa occurred in other stations. Generally, Stn 5 showed to have a prosperity in species number when compared with stations inside the dock.

DISCUSSION

Due to an unique feature of an artificially closed marine ecosystem, viz, isolation from outside saline waters, community structure and dynamics are often different from those in open waters. Moreover, ecological balance is ready to be broken (Hada *et al.*, 1986). Such a breakdown was observed in the present study. Namely sharp decline in the abundance occurred in June 1990 with the oxygen deficiency. At the same time, the abundance of zooplankton increased outside the dock at Stn 5 in coastal waters of the Yellow Sea. According to May (1973), oxygen deficiency seems to control the abundnace of zooplankton especially in closed aquatic ecosystem. Roman and Gauzens (1993) also reported the effects of oxygen deficiency on zooplankton dynamics in Chesapeake Bay. This deficiency might be due to the interruption of water circulation by artificially constructed dock system. Oxgen deficiency seems to be the reason why zooplankton disappeared inside the dock, since anoxic condition was observed at Stns 1-3. Similar pattern of summer oxygen deficiency was reported in southern waters of Korea (Hong, 1987).

Establishment of dense population of *Tintinnopsis tubulosa* only in winter season in Korean waters (Yoo *et al.*, 1988) agrees well with the present result in December 1989. In 1990, maximum abundance 226,000 indiv.m^{-3} was recorded in September at Stn 4 with the prevailence of *Oithona davisae*. Except this month, zooplankton abundances were less than 130,000 indiv.m^{-3} all the year round. *O. davisae* was the species occurred in Korean coastal waters abundantly all the year round (Kim, 1985). Despite extremely high abundance of this species in the present study, it is not uncommon. Hirota and Tanaka (1985) reported even higher abundance in Japanese waters (1,337,321 indiv.m^{-3}: 286, 264 for adult and 1,051,057 for copepodid).

In terms of species number, zooplankton fauna in this study seems to be poor when compared with those of previous studies in the Yellow Sea (Cha and Shim, 1988; Kwak, 1990; Liu, 1990; Sim *et al.*, 1988). This poverty might be due to the study being carried out in a limited area. Rare occurrence of cladocerans seems to be one of reasons, since more than five species of these animals generally occurred in Korean coastal waters (Kim and Onbe, 1989; Yoo and Kim, 1987, 1990).

Acartia bifilosa was the only copepod species distributed in the dock in June 1990. With the occurrence of *A. omorii*, *A. hudsonica* and *A. pacifica*, four species belonging to the genus *Acartia* seemed to success in the studied area. Since Bradford (1976) revised the taxonomy of the genus *Acartia*, taxonomic study on this genus has recently been carried out for Korean specimens (Kang and Lee, 1990). In the present study, *A. bifilosa* and *Paraca-*

lanus crassirostris generally occurred abundantly in summer season.

The reason why *Centropages abdominalis, Pseudodiaptomus marinus, Tortanus forcipatus* and *T. spinicaudatus* were distributed only in waters outside the dock still remains to be obscure.

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