Journal of the Korean Society of Oceanography
Vol. 33, Nos. 1—2, pp. 28—34, June 1998

Seasonal Variations in Distribution, Population Structure and Prosome Length of *Calanus sinicus* (Copepoda: Calanoida) in the Southern Waters of Korea

YOUNG SHIL KANG AND SUNG YUN HONG[1]
National Fisheries Research and Development Institute, Pusan 616-900, Korea
[1]Pukyong National University, Pusan 608-737, Korea

Variations in abundance, size and population structure of *Calanus sinicus* were studied in the southern waters of Korea in connection with hydrographic conditions during 1991—1992. Abundance was high in April and low in August. This species was concentrated inshore of a coastal temperature front, or around the temperature front in April. The 1st—3rd copepodites dominated in February and April, and adults in August. The mean population stages in February and April were younger than those in other survey months. This suggests that this species mainly reproduced during winter—early spring. In prosome length, the 1st—4th copepodites were larger in April than in other survey months, and the 5th copepodite and adult were the largest in February. Mean prosome length of *C. sinicus* showed weak inverse relationship with sea water temperature, but it was not statistically evidenced.

INTRODUCTION

Calanus sinicus is a common copepod in the East China Sea and coastal waters in the North Pacific (Brodsky, 1965; Lin and Li, 1984; Kim, 1985, 1987; Uye *et al.*, 1990). This species is considered as one of the most important zooplankton in the shelf waters in terms of its enormous abundance and large body size, and its significant role as major consumer of primary production and as food for carnivores, including fish (Lin and Li, 1984; Uye *et al.*, 1986).

Hirota (1964, 1979) investigated its seasonal occurrence in the central part of the Inland Sea of Japan. *C. sinicus* occurred in cold season between November and January. Uye (1988), rearing this species in the laboratory with abundant food, reported that its development and growth rates showed maximum at 20.0°C. Huang *et al.* (1993) pointed out that this species was most abundant in June—July and least abundant in October in the Inland Sea of Japan and its neighboring Pacific Ocean. They also noted that the prosome length of late copepodites and adults were inversely correlated with water temperature.

C. sinicus is distributed all around Korean waters in all seasons, and can consitute more than 50% of total copepods during the cold season in the coastal waters (Kim, 1987). This species is a very important secondary producer in the Korean waters, but its production and population growth are little known. Distributional pattern was only recorded by Kim (1985), and the morphological features of each developmental stage were described by Lee (1985). Park and Lee (1995) and Park (1997) estimated egg production, seasonal distribution and feeding of *C. sinicus* in Asan Bay in the western part of Korea.

The present study deals with spatio-temporal variation in abundance of *C. sinicus* in relation to hydrographic conditions. An attempt is also made to elucidate population structure through the composition of each developmental stage and the variations in prosome lengths.

MATERIALS AND METHODS

Zooplankton were sampled at 4 stations from nearshore to offshore in the southern waters in Korea (Fig. 1). A NORPAC net (0.45 m diameter, 0.33 mm mesh) was towed from near bottom to surface during the daytime in October, 1991 and February, April, June, August and October, 1992. The samples were immediately fixed with 10% buffered formalin seawater solution.

In the laboratory adults and copepodites of *Calanus sinicus* were sorted and enumerated. A mean population stage was calculated as:

$$\text{Mean Population Stage} = (NCI \times 1 + NCII \times 2 + \cdots NCVI \times 6)/\Sigma N$$

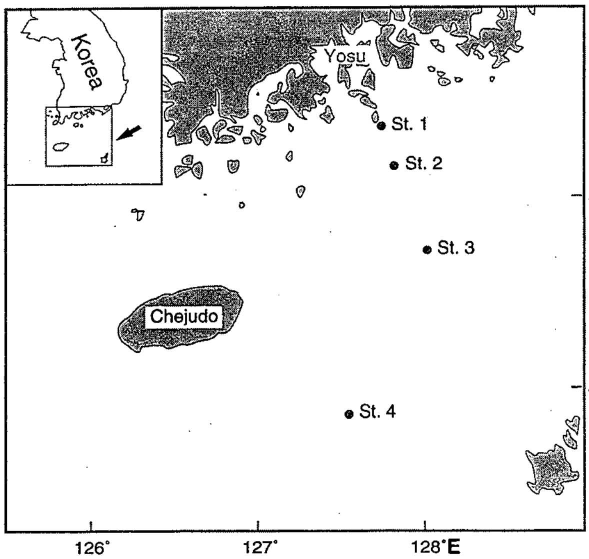

Fig. 1. Map showing the zooplankton sampling stations in the southern waters of Korea.

where NCI, NCII, ⋯, NCVI are the number of specimens of copepodite stage CI, CII⋯CVI and ΣN is the sum of all individuals (Huntley and Escritor, 1991; Schnack-Schiel and Mizdalski, 1994).

Prosome length, from the anterior margin of forehead to the posterior margin of the fifth thoracic segment, was measured in the dorsal view. The water temperature was measured at five different depths, 10, 20, 30, 50 and 75 m with CTD (SeaBird 19).

RESULTS

Hydrology

The water column was vertically well mixed in October, 1991 and February and April, 1992, whereas it was strongly stratified in August and October, 1992 (Fig. 2). Temperature front was formed in October, 1991 and February, April and October, 1992, when thermocline was attenuated or not formed in this area.

Sea water temperature gradually increased from inshore to offshore and decreased from the surface to the bottom. In October, 1991 temperature varied from 20.8°C to 25.9°C and showed sharp gradient between stations 3 and 4. In February, temperature ranged from 10.5°C to 16.8°C and there was a sharp gradient between stations 1 and 2. In April, relatively weak front was found between station 2 and 3. In June, the thermocline began to appear weakly with isotherms running from inshore to offshore with the decay of temperature front. In August strong thermocline was found at the layer of 30—50 m depth. Homogeneous water with > 27°C was present at upper layers of 30 m depth between stations 3 and 4. In October, 1992 thermoclines were formed at two different layers, at 30—50 m depth in stations 1 and 2 and at 50—70 m depth in stations 3 and 4. Temperature front appeared again in this month between stations 2 and 3.

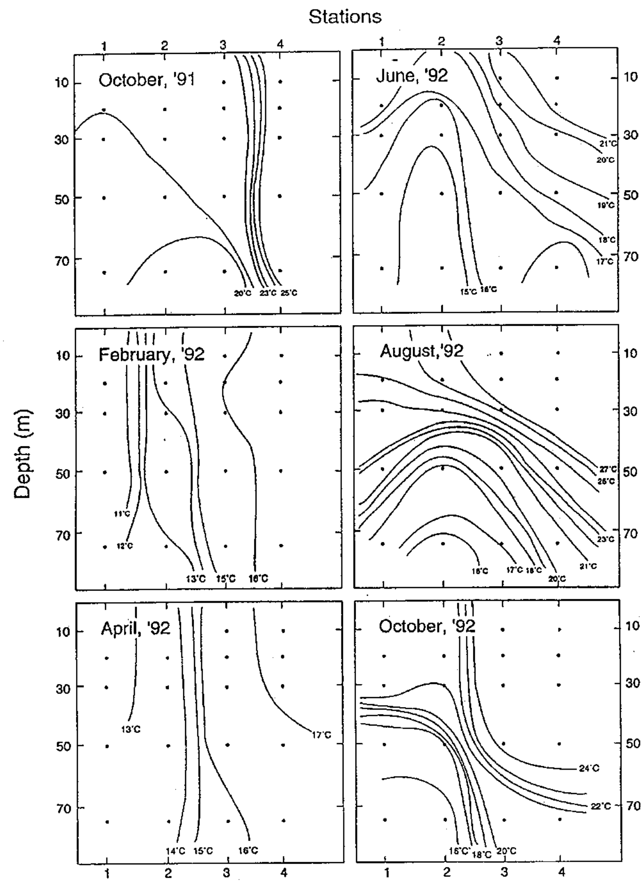

Fig. 2. Vertical distributions of sea water temperature.

Spatial and seasonal variations in abundance and stage composition

Abundance was calculated by summing up adults and all copepodite stages. Monthly mean abundance over the 4 stations ranged from 0.21 to 30.30 inds./m^3 with an annual mean of 10.52 inds./m^3 (Fig. 3). Abundance showed seasonal variation with the maximum in April and minimum in August. Mean temperature was calculated through all survey depths in all stations. The highest temperature appeared in August, while the lowest temperature in February. April also showed very low temperature.

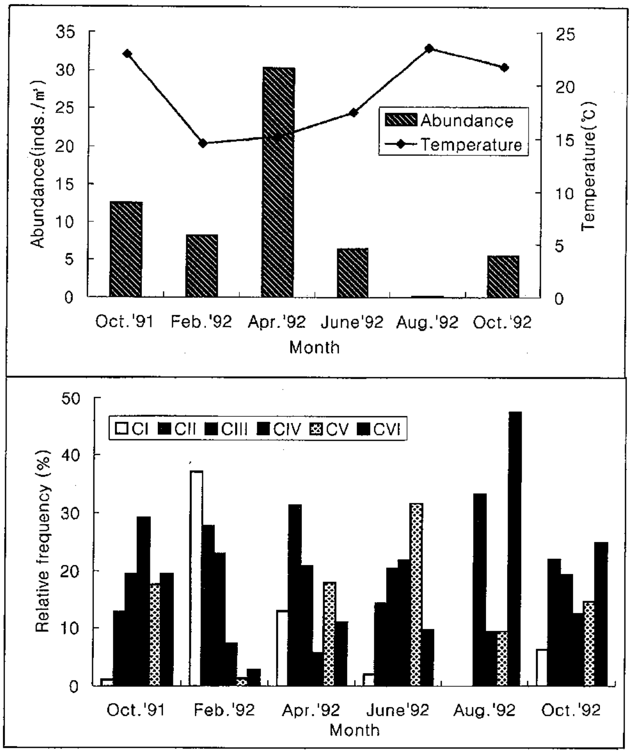

Fig. 3. Seasonal changes in mean abundance (inds./m^3) with mean temperature (°C) calculated through all survey depths in all stations and relative frequency of each developmental stage.

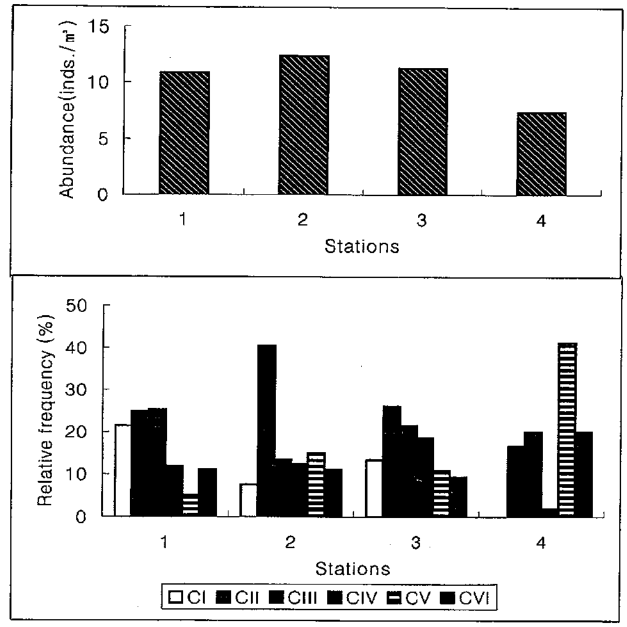

Fig. 4. Geographical changes in annual mean abundance (inds./m^3) and relative frequency distribution of each developmental stage.

Relative frequency distribution of each developmental stages showed that the 1st—3rd copepodites (CI to CIII) predominated in February and April (Fig. 3). The late developmental stages, the 4th and 5th copepodites (CIV, CV) and the adults, began to increase gradually from April and showed the peak in August. CI and CII was not found in August, when adults occupied *ca.* 50% in relative abundance although the total abundance was very low. Annual mean abundance at each station ranged from 7.4 to 12.4 inds./m^3 (Fig. 4). At station 3 located near the temperature front abundance was high, while at station 1 in inshore and station 4 in offshore abundances were low. The earlier stages were more abundant at inshore station, while the later stages at offshore station. At the inshore area CI to CIII was dominated.

Distribution of abundance and vertical profile of temperature are given in Fig. 5. *C. sinicus* was abundant near the inshore area, and rare in the far offshore area with the boundary of temperature front. In April this species was concentrated around the water temperature front. In August this species was not found at station 4 of offshore.

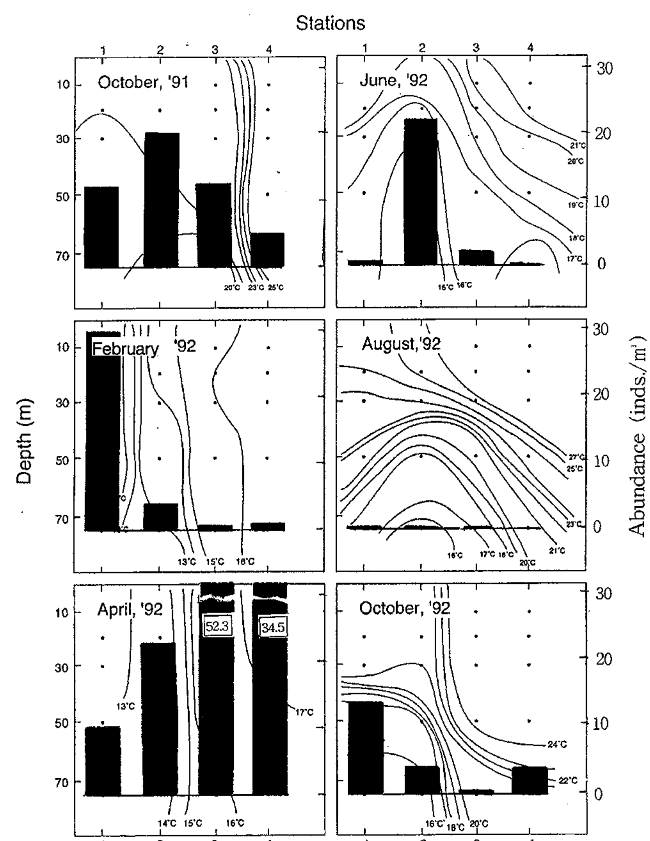

Fig. 5. Geographical distributions of abundance (inds./m^3) and vertical distribution of sea waer temperature (°C).

Seasonal variation in population structure

At station 1 the stage composition usually showed unimodal pattern in all seasons (Fig. 6). The peak shifted from the early developmental stages in February to the late developmental stage in April, and the peak of late developmental stages was sustained until summer, August. The early developmental stages began to appear again from October, 1992. At station 2 the stage composition showed unimodal pattern at all survey months except February. The fraction was fairly even among the stages in October, 1991. The modal peaks were found in the early developmental stages in February and April, and then transferred to the late developmetnatl stages in June. Adults dominated in August and October, 1992. At station 3 the CI to CIII denoted in April, and CIII and CIV dominated through all other survey months. At station 4 the late developmental stages usually dominated, but in April CII and CIII were more abundant than in the other survey months.

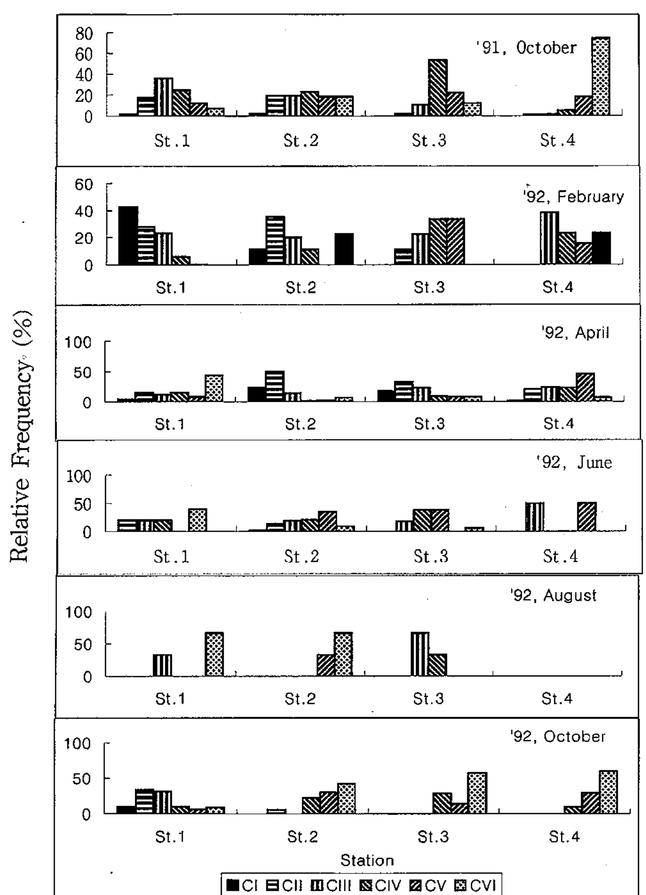

Fig. 6. Seasonal variations in relative frequency distribution of each developmental stage in each station.

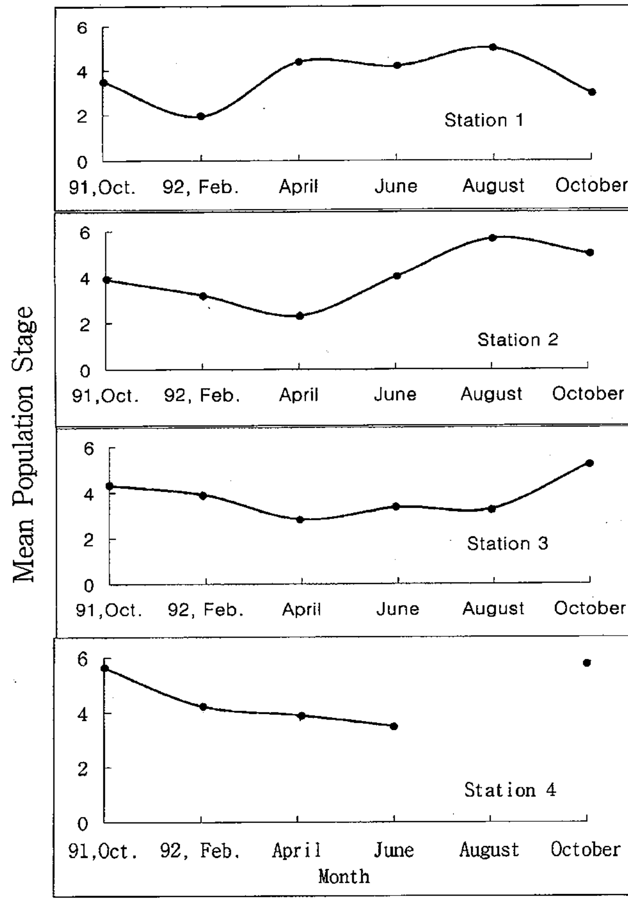

Fig. 7. Seasonal variation in mean population stage in each station.

The variation in the mean population stage is given in Fig. 7. The mean population stage seemed to be younger in winter—early spring (February and April) than in summer—autumn (August and October). The youngest population was found at station 1 in February; at stations 2 and 3 in April; at station 4 in June. On the other hand, the oldest population appeared at stations 1 and 2 in August; at station 3 in October, 1992; at station 4 in October, 1991. At station 3 the mean population stage was fairly similar during April, June and August with 2. 84, 3.37 and 3.32, respectively. At station 4 the mean population stage was older than those at other stations throughout the survey months. It is noted that in August, *C. sinicus* was not found at station 4.

Seasonal variation in prosome length

The prosome length was measured from 3429 individuals. Variation in prosome length was the

Table 1. The mean, standard deviation (SD) and range of prosome length (mm) of *Calanus sinicus* in each developmental stage

Stage	Mean	Range	SD	Number
CI	0.647	0.510—0.807	0.061	434
CII	0.834	0.590—1.082	0.059	767
CIII	1.104	0.807—1.661	0.089	599
CIV	1.412	1.082—2.041	0.126	637
CV	1.876	0.771—2.625	0.158	590
Male	2.074	1.666—2.416	0.132	116
Female	2.224	1.875—2.708	0.142	286

highest in CI, while the lowest in adults (Table 1; Fig. 8). The growth rate, the interstage increment in prosome length, didn't show a particular pattern. Adults revealed low growth rate while, CV high growth rate. The prosome length of CI—CIV showed the maximum value in April, while the minimum value appeared at different months. The CI and CII were not found in August, and their minimum prosome lengths appeared in October. The CIII and CIV were the smallest in August. The CV and adults showed the largest length in February, and the smallest lengths in and August and October, 1991, respectively.

When the mean prosome lengths of each developmental stage were plotted against the mean of sea

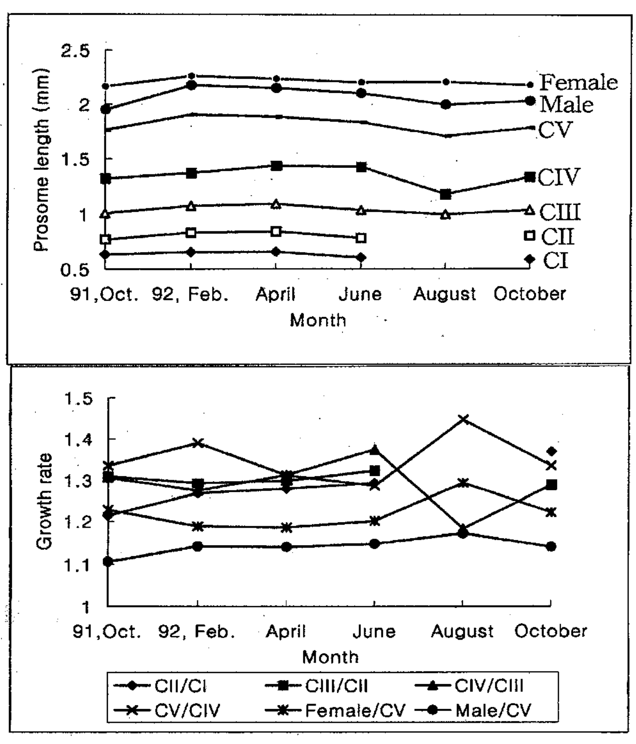

Fig. 8. Seasonal variation in mean prosome length of each developmental stage and growth rate of *Calanus sinicus*.

water temperatures measured from five different depths through the water column, they showed weak negative relationship. However, the slopes of the regression were not significantly different from zero (P > 0.01 F-test).

DISCUSSION

The seasonal variation in abundance of *Calanus sinicus* suggests that this species exhibits a preference of the cold season, winter-early spring. This was also supported by the fact that this species almost disappeared in August from the study area. Huang *et al.* (1993) stated that the upper thermal limit for *Calanus sinicus* was 23°C. Hirota (1979) and Lin and Li (1984) also reported that this species appeared in cold season and disappeared when the temperature exceeded 20—23°C. In this study, the mean temperature through collecting depth in all stations was 15.2°C in April when the abundance showed the maximum value. As regarding the relationship between abundance and mean temperature estimated water column in each stations, high density mainly appeared at the range of 10—15°C temperature.

The food abundance must be considered to discuss the fluctuation of population of *C. sinicus*. Unfortunately, chlorophyll-*a* was not estimated in this study. It is conceivable that phytoplankton biomass is high in spring in the temperate seas.

C. sinicus was more densely populated in the inner area than the outer area delineated by temperature fronts through all survey months except April. It suggests that temperature front affects the distribution of *C. sinicus*. This phenomenon was especially apparent in February when a strong temperature front appeared at the most inner area. This is in good agreement with Huang *et al.* (1993), who showed that the biomass of *C. sinicus* was much denser and fluctuated more in the coastal waters than in offshore waters. They considered that lower population abundance in offshore water was apparently related to scare food supply. We could not consider the supply of phytoplankton food in the study area. However, it was clear that the phytoplankton was more abundant in the coastal area than in the offshore Korean waters (Choe, 1969).

In April *C. sinicus* was mainly concentrated around the water temperature front. It is well known that productivity along temperature fronts was high.

Uye *et al.* (1992) studied the relationship between the fluctuation of copepod density and the effect of water temperature fronts. They concluded that the frontal population was subjected to higher mortality, probably due to predation by carnivores, so copepod density was very low around the temperature front. The present study was not consistent with Uye *et al.* (1992). Another influence must be the fact that the temperature front dose not serve as a barrier against the extension of distribution of the late developmental stages. The 1st—3rd copepodites were usually concenturated at the inner area of the temperature front. As the stages progressed, their distribution extended across the temperature front. This is in agreement with Huang *et al.* (1993), who worked on the geographic distriubtion of the stage composition of *C. sinicus*. They pointed out that the annual mean percentage of young copepodites (*i.e.*, CI and CII) was higher in the coastal areas than in the offshore Pacific, but the composition of CV and the adults was inversely related. Considering above facts, it can be recognized that the more this species grow up the more tolerance on temperature they have.

The mean population stage and stage composition make it possible to infer that the reproduction of *C. sinicus* takes place intensively in late winter/early spring, although it occurs throughout the year except August. Lin and Li (1984) reported that *C. sinicus* had three main breeding periods (December —mid-February, the end of March—April and mid-May) in Xiamen Harbor. In contrast to Lin and Li (1984), Huang *et al.* (1993) pointed out that the reproduction of *C. sinicus* took place continually in Inland Sea of Japan and the population was devoid of diapause in the seasonal life cycle, though they did not refer to the main period in reproduction. Park and Lee (1995) reported that egg production of *C. sinicus* showed two peaks, spring and fall in Asan Bay, on the west coast of Korea. They also mentioned that this species might reproduce year round and horizontally migrate seasonally. From these findings, it may be concluded that *C. sinicus* reproduces continually through the year except summer, August, with the main breeding periods in late winter/spring, in the southern waters of Korea. Park (1997) also reported that *Calanus sinicus* showed one peak in spring in abundance and two peaks in spring and fall in egg production in Asan Bay.

It is a general feature for copepods that the lower the temperature during the development period, the larger body size (McLaren, 1965; Kimoto *et al.*, 1986; Uye, 1988, 1991). This study on *C. sinicus* showed very weak negative relationship between prosome length and sea water temperature. But the slopes were not statistically significant. Thus, the relationship between prosome length and sea water temperature was not statistically evidenced in this study.

ACKNOWLEDGEMENTS

We thank Drs. Chul Park and Michael Mullin for insightful comments on this manuscript.

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Manuscript received September 14, 1997
Revision accepted January 20, 1998