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The Resting Eggs of Marine Cladocerans in the Intertidal Sea-bottom Sediments of Gomso Bay, Korea: Distribution and Evidence of Egg Banks

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We investigated the distribution of the marine cladoceran resting eggs in the intertidal sediments of Gomso Bay, Korea and compared the data with those in the subtidal sediments. The abundance of the eggs in the top 6 cm of the sediments was higher than that in the other depths. The abundances of the eggs in seaward intertidal sediments below mean sea level (MSL) were higher than those in the sediments over MSL, but were not significantly different from those in the subtidal sediments. The distribution of the resting eggs of cladocerans in the intertidal sediments was affected by the grain-size and moisture content of sediments. The results of the present study suggest that the intertidal sediments as well as the subtidal sediments are a potential egg bank which plays important roles in population dynamics of zooplankton in coastal waters, in particular, recruitment of eggs into plankton.

Key words: resting egg, distribution, intertidal sediment, egg bank, Cladocera

Introduction

Some zooplankton populations suddenly disappear from the water column in a certain period and then reappear other periods. Their reappearances are usually resulted from the hatching of the resting eggs in the bottom sediments (Kasahara and Uye, 1979; Onbé, 1985; Marcus, 1995).

Many marine and freshwater zooplanktons produce the resting eggs to survive under unfavorable conditions (Madhupratap et al., 1996; Hairston, 1996) such as extremely low or high temperature (Grice and Marcus, 1981; Ban, 1992), short-day photoperiod (Marcus, 1980; Ban, 1992), high predation pressure (Hairston and De Statio, 1988), population density (Ban, 1992) and depletion of food (Onbé, 1991).

The resting eggs sink and stay in the bottom sediments due to their gravity (Marcus and Taulbee, 1992). Benthic resting eggs of zooplankton have been reported from many coastal areas, indicating the potential importance of the bottom sediment for egg banks (Marcus, 1984, 1990; Onbé, 1991; Madhupratap et al., 1996; Hairston, 1996).

To understand the population dynamics and life cycles of zooplankton, information on the distribution, longevity, mortality and hatching of the resting eggs in the bottom sediment is required. In addition, as Marcus (1995) and Marcus and Boreo (1998) suggested, information on benthicpelagic coupling will be necessary. However, all the studies on the distribution of marine zooplankton resting eggs have exclusively been carried out in the subtidal zone of the coastal areas (Kasahara and Uye, 1979; Onbé, 1985; Marcus, 1990; Viitasalo, 1992; Viitasalo and Katajisto, 1994). There has been a study dealing with the distribution of the resting eggs in the intertidal sediments, in particular, paying attention to the hatching of calanoid copepods (George and Lindley, 1997).

West coasts of Korea have the intertidal zone

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which is as wide as 10 km in maximum and whose slope is gentle (Je and Choi, 1998). There may be high abundance of resting eggs in the sediment of the zone and the eggs may play an important role in recruitment for coastal plankton.

The present study explores the distribution of cladoceran resting eggs in the intertidal sediments of Gomso Bay, west coast of Korea, and determines a potential of egg bank of intertidal flat. The distribution patterns of the eggs in the intertidal sediments are compared with those in the subtidal sediments.

Materials and Methods

Study area

The study area is located north side of Gomso Bay, west coast of Korea, which is 20 km long and 7~9 km wide, and characterized by its shallow mouth, a long main tidal channel and broad intertidal zone (Fig. 1). The bay mouth is as relatively shallow as 6~8 m deep with a flat sea-bottom. The main tidal channel develops well along the northern side with the deepest depth of 18.5 m and the widest width of 900 m. The tidal zone occupies most of the bay, accounting up to 75 km^2 (Chang et al., 1996). The tide of Gomso Bay is semi-diurnal without diurnal inequality, of which the mean and maximum tidal differences are 433.8 cm (589.8 cm at spring tide and 277.8 cm at neap tide) and 717.4 cm, respectively (Chang, 1995).

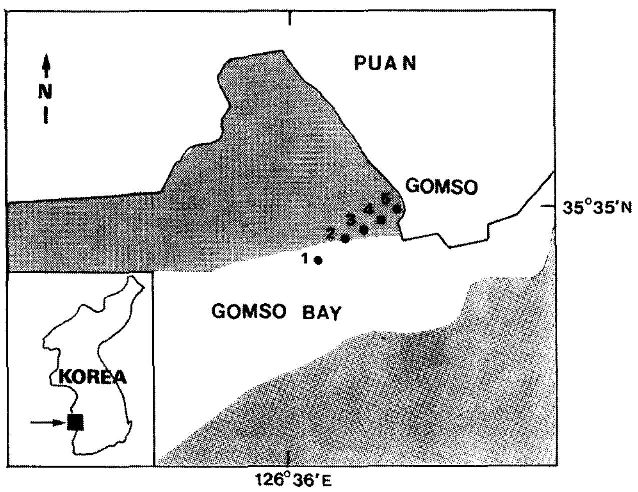

Fig. 1. Location of the sampling stations in Gomso Bay. Shaded area denotes intertidal flat.

Collection of sediment

Triplicate sediment samples were collected from the five stations with a hand-made corer (ϕ 6 cm, L 50 cm, pvc) at low tides on February 20, April 5 and May 10, 1997. Station 1 was located in the subtidal zone, stations 2 and 3 were located between the subtidal zone and mean sea level (hereafter, referred to as MSL), and stations 4 and 5 above MSL (Fig. 2).

Sediments in the subtidal zone were carefully collected from a 5 m depth by a SCUBA diver with minimizing disturbance. The sediments were transported to the laboratory within two hours and stored in the dark at 3℃.

Analysis of sediment

The sediment samples were sieved into two gradients by size (coarse and fine sediments) using wet sieving method (63 μm) after adding H_2O_2 (80 %) to eliminate organic matters in the sediments. Sands were sieved with a roetap sieve shaker for 15 minutes to measure the composition percentage by 0.5 ϕ size (Ingram 1971). Percentage of sediment moisture content also was determined using the following equation: percentage of sediment moisture content (%) = 100 × (wet weight − dry weight) / wet weight. Dry weight was measured after drying wet sediments in an oven at 110℃ for two hours.

Isolation and identification of eggs

Three days later after the sediment collection, the sediments were cut at 2 cm intervals up to 10 cm depth. Each sample was shaken, sonicated for 30 seconds (Branson 8210) and filtered through 55 μm mesh. The remaining materials on the sieve were extracted carefully with sugar floatation technique (Onbé, 1978; Marcus, 1990) and centrifuged at 3,000 rpm for 3 minutes (Vision VS-5500). The supernatant was washed thoroughly in a 55 μm sieve with filtered seawater, and transferred to a petri dish for the enumeration of the eggs. The eggs were sorted based on the egg shape and size under microscopes (Zeiss Stemi SV6; Nikon Optiphot-2). For identification of the eggs, Onbé (1973, 1977, 1985), Marcus (1990), Viitasalo & Katajisto (1994), and Madhupratap et al. (1996) were referred. For more

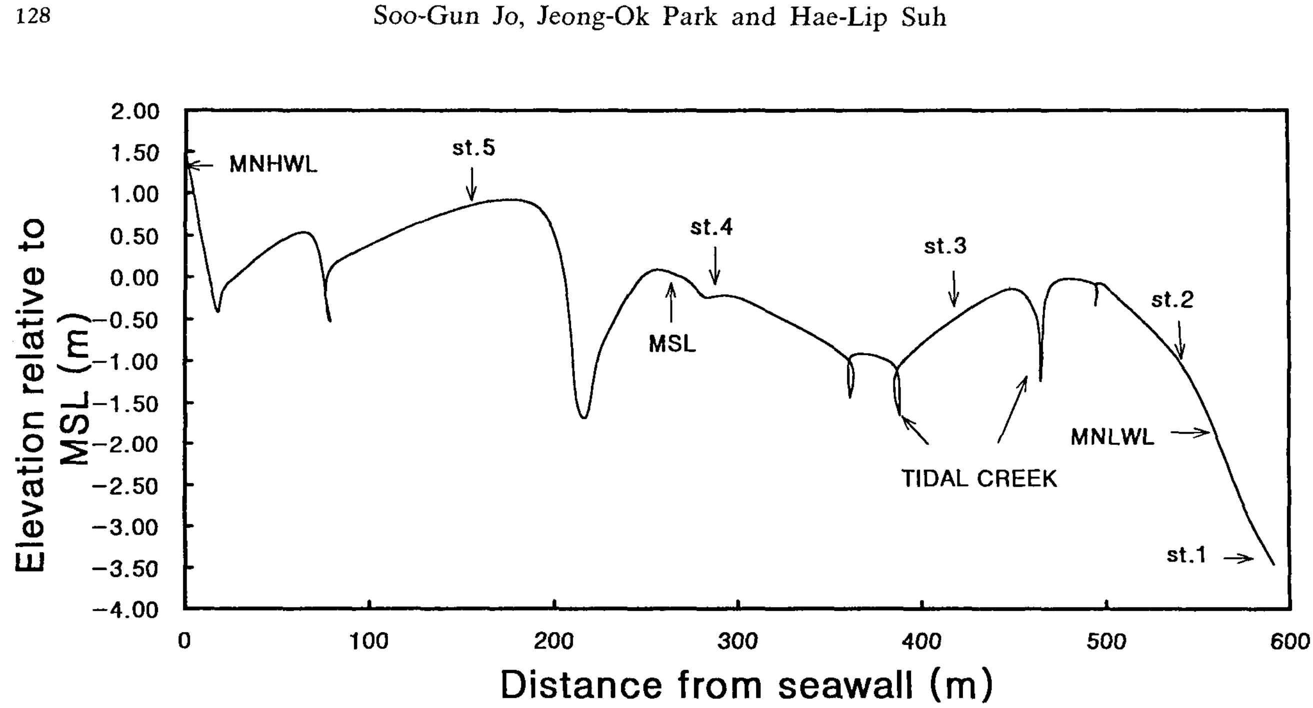

Fig. 2. The profile of the tidal flat of the sampling stations, Gomso Bay. MNHWEL=mean neap high water level; MNLWL=mean neap low water level.

precise identification, different kinds of eggs were incubated in a cylindrical plastic vessel (ϕ 3 cm, H5 cm) with a bottom attached 50 μm mesh which was kept in a aquarium (25×45×25 cm) filled with ambient filtered seawater at 20 ± 0.2℃ and on a 12 light : 12 dark cycle.

Results

Profile and sediment properties of the study sites

The slopes of the study sites were measured by observing the location of deflection points on a line vertical to the coast line with a Total Station (TC 2002, Leica, Fig. 2). In the study sites, several tidal creeks appeared, one of which was as deep as 1.5 m, indicating that strong tidal currents were prevailing there. The sediment type in the study area was principally silt (Table 1) and the mean grain size of the sediments ranged from 5.3 to 5.8 ϕ with a sorting of 2.2~2.4 ϕ. And the closer the sediment became to seaside, the more the percentage of silt decreased, while the more the percentage of sand increased.

Egg morphology

The eggs of the cladoceran, *Penilia avirostris, Evadne trigestina*, and *Podon polyphemoides* were found in the collected sediment (Fig. 3). The eggs of *P. avirostris* (minor and major(± sd) diameters: 183.0(± 3.2) and 249.0(± 2.5) μm) were grey and oval under light microscopy (Fig. 3A). The eggs of *E. trigestina* (dia. 212.7 ± 16.0 μm) were dark brownish or golden with a smooth surface (Fig. 3C). The eggs of *P. polyphemoides* (dia. 184 ± 13.2 μm) were brown-greenish and spherical with a granular surface (Fig. 3E).

Table 1. Sediment moisture content (SMC) and characteristics of the first 10 cm of the sediment at each station, Gomso Bay

Station	Sediment type	SMC (%)	Mean (ϕ)	Sorting (ϕ)	Sand (%)	Silt (%)	Clay (%)
1	silt	under water	5.3	2.4	18.6	67.9	13.5
2	silt	21.4	5.4	2.4	18.5	68.6	12.8
3	silt	20.1	5.5	2.4	21.1	66.3	12.6
4	silt	16.8	5.7	2.3	11.8	75.7	12.6
5	silt	17.4	5.8	2.2	5.9	82.5	11.6

Horizontal distribution

The patterns of the horizontal distribution in the resting eggs in the upper 10 cm bottom sediments were affected by both species and sampling periods (Fig. 4). In general, however, almost all the eggs were found at the subtidal (st. 1) and lower two

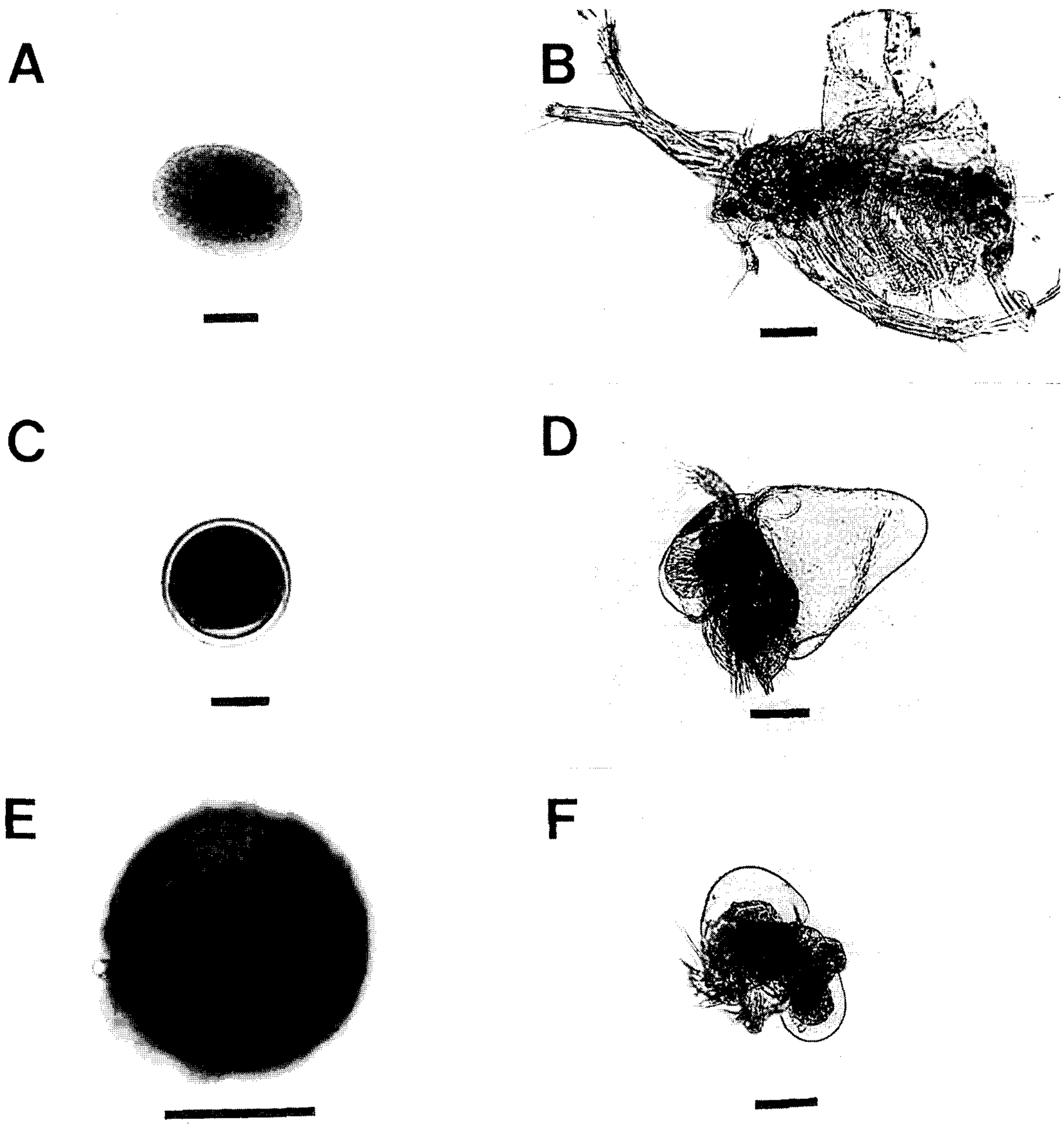

Fig. 3. Photomicrographs of the resting eggs and juveniles of marine cladocerans after hatching. A, B, *Penilia avirostris*; C, D, *Evadne trigestina*; E, F, *Podon polyphemoides*. Scale bars = 100 μm.

stations (sts. 2, 3) below MSL while few eggs were found in the upper stations (sts. 4, 5).

In *P. avirostris*, the egg abundance was highest in either the lowest intertidal station or sometimes subtidal station, with the mean densities of 6.4~19.2 eggs/cm^2. On the other hand, at the upper two stations, the abundances were zero or very low. The abundance of eggs of *P. avirostris* in the lower part of the intertidal sediments was higher than that in the upper one.

The egg abundances of the stations below MSL were significantly different from those above MSL, but they were not different from those of the subtidal station below MSL (Table 2).

In *E. trigestina*, the egg abundance was highest at the two stations below MSL, with the mean

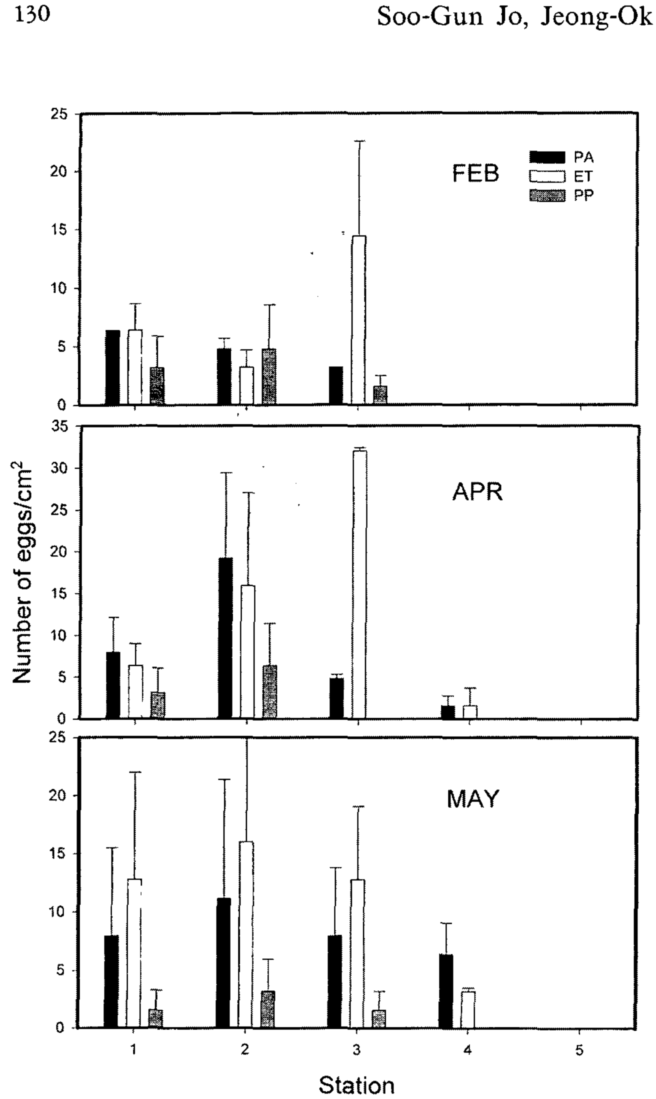

Fig. 4. Average abundances (+SD) of the marine cladoceran resting eggs in the top 10 cm of bottom sediments at the different stations in February, April and May.
PA: *Penilia avirostris;* ET: *Evadne trigestina;* PP: *Podon polyphemoides.* (st. 1, subtidal; sts. 2~5, intertidal)

densities of 14.4~16.0 eggs/cm². In the upper two stations, no or few eggs were found. The statistical differences were significant as found in *P. avirostris* (Table 2).

In *P. polyphemoides,* high egg abundances were found in the stations below MSL, with the mean densities of 3.2~6.4 eggs/cm². In the upper two stations, no eggs were found. The differences between the stations below and above MSL, and between the subtidal station and the stations below MSL were not significant although there was a significant difference between the two stations themselves below MSL (Table 2).

Table 2. Comparison of the abundances of marine cladoceran resting eggs between two different sampling stations

Stations compared	*Penilia avirostris*	*Evadne trigestina*	*Podon polyphemoides*
1 : 2	–	–	–
1 : 3	–	–	–
1 : 4	***	***	**
1 : 5	****	****	**
2 : 3	–	–	**
2 : 4	–	****	****
2 : 5	****	****	****
3 : 4	–	**	–
3 : 5	****	****	–
4 : 5	–	–	–

Significance levels: -not significant; *$p<0.05$; **$p<0.025$; ***$p<0.01$; ****$p<0.005$

Vertical distribution

The vertical distributions in the resting eggs in the top 10 cm sediments were affected by species, sampling stations, and sampling months (Figs. 5~7, Table 3).

In general, however, most eggs of the three species were found in the top 6 cm depth and the maximum densities were usually found there.

Resting egg abundance in relation to the grain size and moisture content of sediment

The relationship between the resting egg abundance and the sediment characteristics of the intertidal flat was examined (Table 1, Fig. 8). The mean grain size of bottom sediments decreased from landwards toward seaside, ranging from 5.3 to 5.8 ϕ, while the moisture content in the intertidal sediments increased from 16.8 to 21.4 percent. The egg abundances of the three species increased with the grain size of bottom sediments decreasing while the moisture content of the sediments increased.

Discussion

Four species of the cladocerans, *E. nordmanni, E. tergestina, E. spinifera,* and *P. avirostris,* have been reported in the Korean waters (Shim and Lee, 1983; Shim and Yun, 1990; Hwang and Choi, 1993; Kim et al., 1993). Of these, all species but *E. spinifera* are known to produce resting eggs (Onbé, 1973; Marcus, 1990; Madhupratap et al., 1996), so the

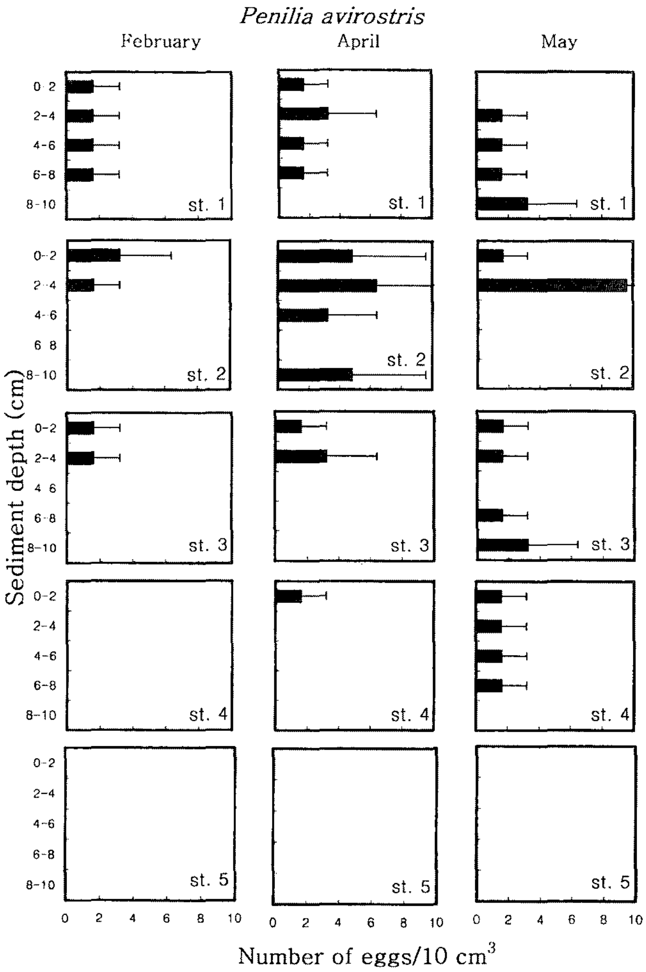

Fig. 5. Vertical distribution of *Penilia avirostris* resting eggs in the first 10 cm of the sediment at the different stations in February, April and May. (st. 1, subtidal; sts. 2~5, intertidal)

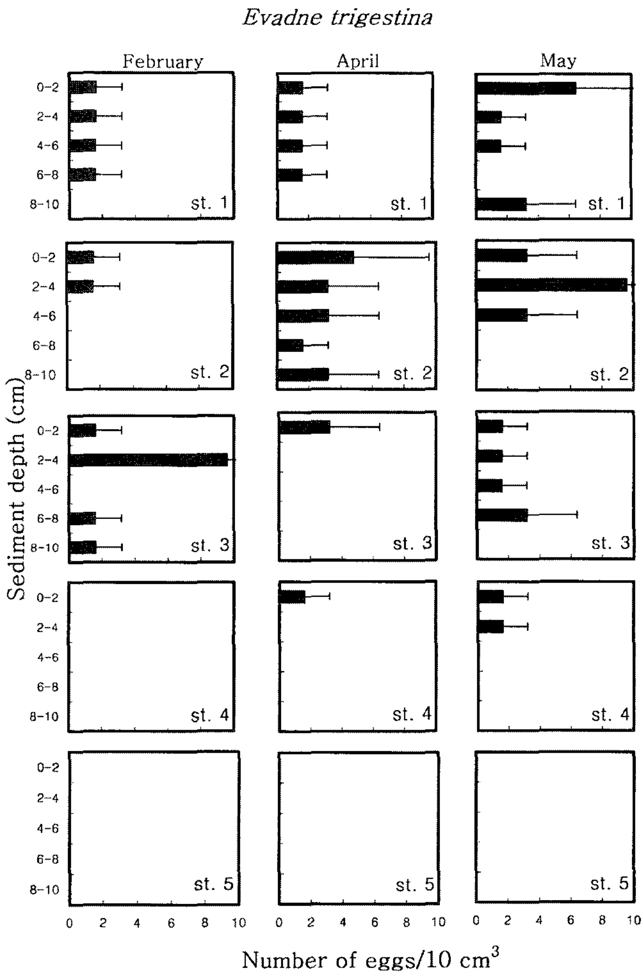

Fig. 6. Vertical distribution of *Evadne trigestina* resting eggs in the first 10 cm of the sediment at the different stations in February, April and May. (st. 1, subtidal; sts. 2~5, intertidal)

Table 3. Comparison of the abundances of marine cladoceran resting eggs between sediment depths

Sediment depths compared	*Penilia avirostris*	*Evadne trigestina*	*Podon polyphemoides*
2 : 4	–	–	–
2 : 6	–	–	–
2 : 8	*	**	–
2 : 10	–	***	–
4 : 6	*	–	*
4 : 8	*	–	**
4 : 10	**	*	**
6 : 8	–	–	–
6 : 10	–	–	–
8 : 10	–	–	–

2, 4, 6, 8 and 10 denote the sediment depths of 0~2, 2~4, 4~6, 6~8 and 8~10 cm, respectively. Significance levels: -not significant; *$p<0.05$; **$p<0.025$; ***$p<0.01$; ****$p<0.005$.

occurrences of their resting eggs in this study might be expected. In the present study, the resting eggs of *E. nordmanni* were not found. However, the resting eggs can be present in the sediments because the adults have been reported to be present at very low densities (Shim and Yun, 1990; Hwang and Choi, 1993).

P. polyphemoides has not been reported to be present in Korean waters, but we found its resting eggs. Therefore, its adult may be present after hatching.

According to the previous studies (Onbé, 1973; Madhupratap et al., 1996) and the result of the present study (Fig. 3), all the eggs collected during this study were of diapause. The diapause eggs

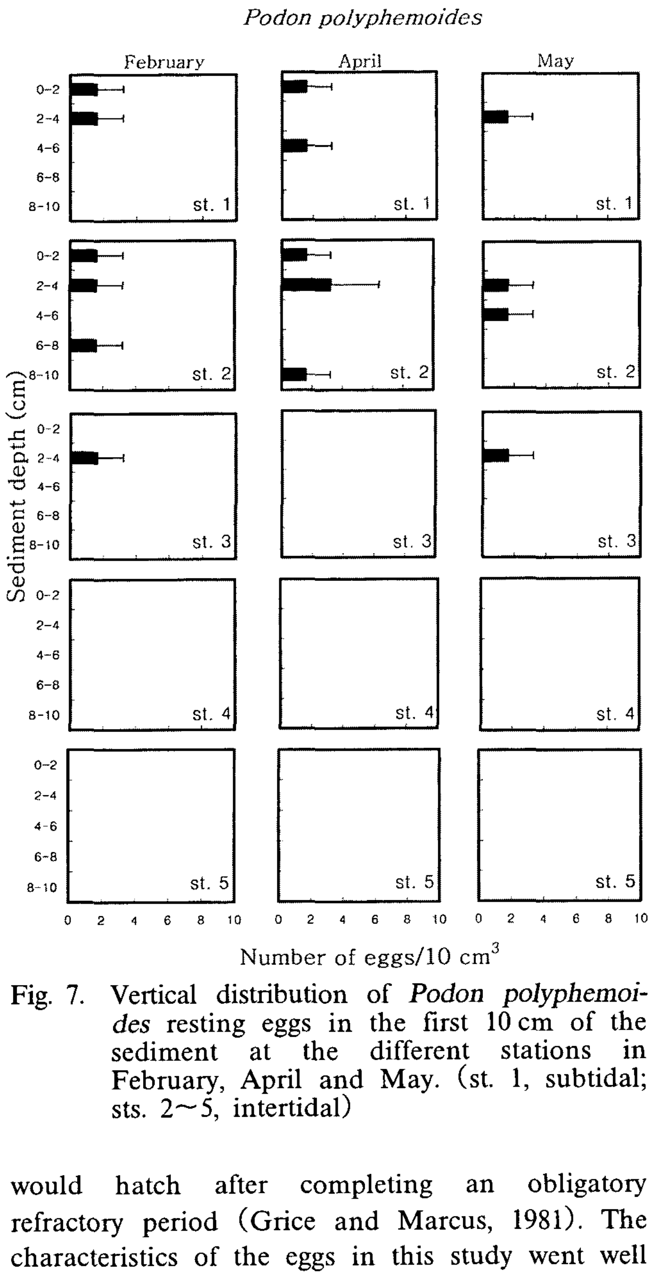

Fig. 7. Vertical distribution of *Podon polyphemoides* resting eggs in the first 10 cm of the sediment at the different stations in February, April and May. (st. 1, subtidal; sts. 2~5, intertidal)

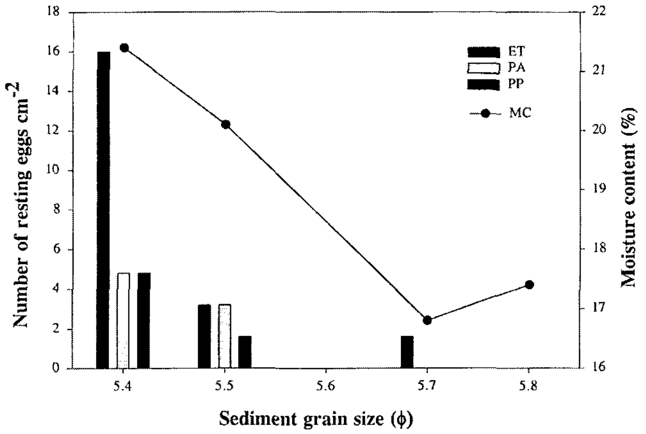

Fig. 8. The relationship between the abundance of the marine cladoceran resting eggs and the grain size and moisture content of the sedi-ment, Gomso Bay, Korea. ET: *Evadne trigestina;* PA: *Penilia avirostris;* PP: *Podon polyphemoides;* MC: Moisture content of the sediment.

would hatch after completing an obligatory refractory period (Grice and Marcus, 1981). The characteristics of the eggs in this study went well with the diapause eggs described by the previous studies (Onbé, 1973; Madhupratap et al., 1996) and, in Korean and its adjacent waters, the adult cladocerans, such as *E. tergestina* (Onbé, 1985; Shim and Yun, 1990; Hwang and Choi, 1993), *P. avirostris* (Shim and Yun, 1990; Hwang and Choi, 1993) and *P. polyphemoides* (Onbé, 1985), had not appeared in plankton samples from February to May when the eggs were present.

Onbé(1985) reported the abundance of some cladocerans including *E. tergestina, P. avirostris* and *P. polyphemoides* in the bottom sediments of a subtidal zone in the Inland Sea of Japan. However, the quantitative study on the abundance of zooplankton resting eggs in the intertidal zone has never been in detail studied yet although George and Lindley (1997) reported the study in the intertidal estuary sediments which was focused on the hatching experiment of copepod resting eggs. In this study, the maximum densities of the resting eggs of *E. tergestina, P. avirostris* and *P. polyphemoides* in the intertidal bottom sediments (approximately, 2×10^5, 2×10^5, 7×10^4 eggs/m^2, respectively) are comparable to those from the subtidal zone of Japan by Onbé(1985). In addition, in this study, there were no differences in the abundances of the resting eggs between intertidal sediments below MSL and subtidal bottom sediments, suggesting that intertidal bottom sediments as well as subtidal ones are considerably important as a resting egg reservoir. Especially in coastal waters with a greatly large area of intertidal zone as in western Korea, the intertidal zone should play an important role in the population dynamics of zooplankton through recruitment of individuals hatched from resting eggs into plankton.

The resting egg distribution in the intertidal sediments might be affected by physical, biological, and chemical factors or their combinations. In the present study, more abundances of the cladoceran resting eggs were found in the sediments <5.6 ϕ in mean grain size than in the sediments >5.6 ϕ. As a result of a laboratory simulation, Marcus and Taulbee (1992) suggested that the distribution of copepod eggs in the bottom sediments should be highly affected by the grain-size composition of sediments. Although we did not perform laboratory simulation such as the sinking velocities and distribution of eggs in the laboratory, the present results also show that the abundances of the cladoceran eggs are affected by the sediment grain size.

Most zooplankton eggs were so small and spherical that the ratio of surface area to volume increases and, as the result, the eggs, even if they are of diapause, may be not tolerant of descication. In that respect, the moisture content in the intertidal sediment might also be important in survival of the eggs. In the present study, higher abundances of the cladoceran resting eggs were found in the sediments with higher moisture content, explaining that more resting eggs were found in seaward intertidal zone below MSL.

The horizontal distribution of the resting eggs in the intertidal sediments also might be affected by the exposure time due to tide. Because seawater generally stays longer time in the lower part of tidal zone than in the upper area, eggs in suspension will take much more opportunities to sink to the bottom of the lower part. Marcus et al. (1994) reported that most viable eggs occurred in the top 5 cm of sediment and that the egg hatching success gradually decreased with increasing depth due to their exposure to anoxia and H_2S for a long time. In this study, the abundance of the eggs was usually higher in the top 6 cm of sediment than below 6 cm. Vertical distribution of zooplankton eggs can be mainly affected by winds, waves, tide currents, toxic materials, anoxic condition, predation by benthic animals, and bioturbation, etc (Marcus, 1986; Marcus and Lutz, 1994). Of these, seasonal strong winds and strong tidal currents with a maximum tidal difference of 714 cm are characteristic in the present study area, where the annual accumulation rates in the tidal flat are about 41 mm/year, with monthly accumulations being 1.9~6.4 mm/month, −8.3~2.1 mm/month and 0.5~14.4 mm/month in summer, fall and winter, respectively (Chang, 1995). Therefore we suggest that physical accumulation or erosion by strong tidal currents or winds may play a major role in determining both vertical and horizontal distributions of zooplankton eggs and affect the burial and hatching of the eggs in the tidal sediments of Gomso Bay, Korea.

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