pISSN (print) 1226-9999
eISSN (online) 2287-7851

Korean J. Environ. Biol. 31(2) : 165~171 (2013) http://dx.doi.org/10.11626/KJEB.2013.31.2.165

Distribution Patterns of Calanoid Copepods along the Seomjin River Estuary in Southern Korea during Summer

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Abstract - The distribution patterns of estuarine copepods were investigated in the Seomjin River estuary of southern Korea after heavy rains in August 2006. Tidal influence extended 16 km from the estuary mouth. Each estuary zone (Oligohaline salinity <5, mesohaline salinity 5～18, polyhaline salinity >18) changed within a range of about 5～6 km between low and high tides. A total of ten species were recorded, of which *Pseudodiaptomus koreanus*, *Sinocalanus tenellus*, and *Tortanus dextrilobatus* were predominant in the oligohaline zone; *Acartia ohtsukai* and *Acartia forticrusa* in the mesohaline zone; and *A. erythraea*, *Calanus sinicus*, *Centropages dorsispinatus*, *Labidocera rotunda* and *Paracalanus parvus* s. l. in the polyhaline zone. Their density was fastly reduced in the other zones. In particular, the oligohaline species migrated and aggregated into deeper water during ebb tides in order to retain their populations, while the same tendency was weaker for polyhaline species, suggesting that evolutionary traits primarily control population retention behaviors in estuarine environments.

Key words : estuarine copepods, Korean estuary, heavy rains, salinity gradients, tides

INTRODUCTION

Behavioral adaptations promoting retention within geographical areas seem to be important in marine zooplankton (Kaartvedt 1993; Schlacher and Wooldrige 1995), and such behavior may decrease the actual influence of advection on population dynamics. In particular, migration pattern and retention strategy in tidal estuaries are closely related to the ecological processes of that estuary. Tides determine habitat accessibility for tidal migrating species while the semi-diel cycle actively controls visual conditions and diel changes in organisms. These ecological processes, such as instantaneous variations in salinity caused by tides, increase the mortality rate of early copepod stages. Although copepod position in the water column is greatly affected by water movements such as tides and currents, they are not totally at the mercy of these influences and have been known to migrate vertically and horizontally (Morgan *et al.* 1997; Kimmerer *et al.* 1998). However, it is still not fully clear how much of copepod movement is caused by tides and how much is in response to the surrounding physical environment. Although vertical migration has been observed to occur at specific tidal periods (Wooldridge and Erasmus 1980), varying migration patterns are exhibited by different copepod species and even intra-species in different environmental settings, which is more complicated by their species-specific life strategies (Head *et al.* 1985; Hays *et al.* 2001). However, tides have often been regarded as playing a constraining role on migration.

Several reports have indicated that, despite their weak

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power of locomotion, some species of zooplankton occurring in estuaries can actively cope with tidal transportation and remain at their preferred salinity concentrations (Cronin *et al*. 1962; Wooldridge and Erasmus 1980; Collins and Williams 1981; Hough and Naylor 1991; Kimmerer *et al.* 1998; Ueda *et al.* 2004; Park *et al.* 2005). Moreover, other reports have indicated that the pattern of species appearance in estuaries is related not only to salinity but also to temperature, food, turbidity, tides and other factors (Castel and Veiga 1990; Jerling and Wooldridge 1991; Laprise and Dodson 1994).

In this study we aim to highlight the effect of tide controlling horizontal distribution of some calanoid copepods along the Seomjin River estuary, Korea during the rainy season of August.

MATERIALS AND METHODS

1. Study area

The Seomjin River is 226 km long, making it the ninth-longest river in Korea. The basin area is 4,897 km^2, covering southeastern Jeollabuk-do as well as eastern Jeollanam-do and western Gyeongsangnam-do provinces. Water depth in the estuary averages at 7～8 m. Average annual rainfall is 1,253 mm, with over 70% falling in summer. Tides affects to about 18 km in the upper stream from the mouth of the Seomjin River estuary. The sampling stations are showed in Fig. 1.

2. Sampling methods

The field survey was conducted August 9th 2006. All copepods were deep horizontally towed near bottom at the speed of 2 knots from 17 stations during flood and ebb tides along a gradient salinity using a NORPAC net (mesh size 200 μm; mouth diameter 45 cm) during 5 minutes. Distance between each station was about 1 km. Sampling was over within 3 hours starting at each high and low tide using a high speed boat. Water temperature and salinity were measured by 600 MKIII CTD (UK, Valeport) and ACL 1150- DK (Japan, Alec co.).

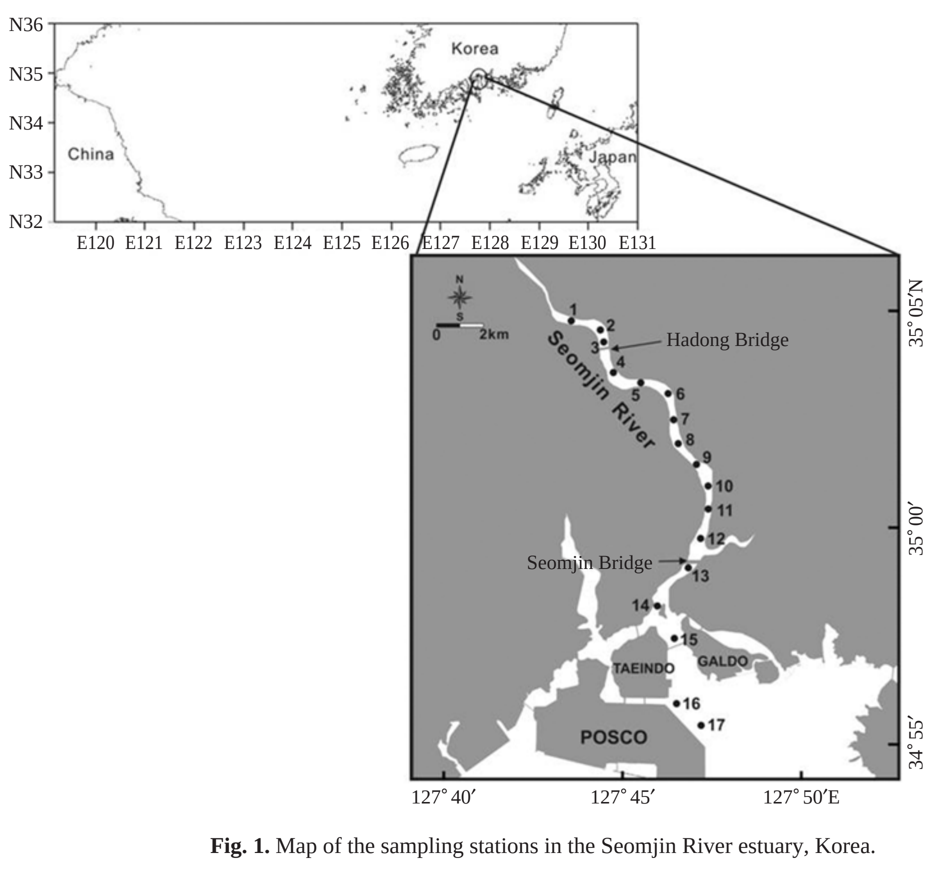

Fig. 1. Map of the sampling stations in the Seomjin River estuary, Korea.

Abundance of copepods were estimated from rotations of a flow meter (General Oceanics co.) attached to the net mouth. After samples were immediately preserved in a 5% neutralized formalin and estuarine water solution, copepods were identified at a species level and counted using light stereomicroscopes (Nikon) according to their identification characteristics. According to Ekman's classification system (Day *et al.* 1989), there are three salinity divisions in the estuarine zone; oligohaline salinity (0∼5.0), mesohaline salinity (>5.0∼18.0), and polyhaline salinity (>18.0).

Rainfall data from the study area were provided by the meteorological agency (http://www.kma.go.kr/).

3. Statistical analysis

For correlation to detect any significant density differences among the stations at specific tides, and between high tide and low tides, ANOVA and student's t-test analysis were carried out using SPSS (Version 12). Data were log (X+1)-transformed for the statistical analyses. The density of copepods was calculated by ind.m^{-3}.

RESULTS

1. Tides and salinity

Salinity was in the range of 0.1 to 29.3 for the 17 stations. Salinity of less than 1.0 was found in the upper stream beyond station 5 in high tide, while being noted as far back as station 9 in low tide. Salinity of more than 18.0 was found downstream of station 11 in high tide, reducing to 16.0 in low tide (Fig. 2). In particular, salinity fluctuated strongly during high tide and followed the same pattern in low tide.

At both high and low tides, copepod abundance was high at salinity of 20.0∼23.0 and low at salinity of <2.0.

2. Copepod populations and their density

In total, ten copepods were recorded from the Seomjin River estuary. Among them the major copepods were *Tortanus dextrilobatus*, *Pseudodiaptomus koreanus*, *Acartia ohtsukai*, *Sinocalanus tenellus* and *Paracalanus parvus* s. l., while other minor copepods taxa were *Calanus sinicus*, *Acartia forticrusa*, *Centropages dorsispinatus*, and *Labidocera rotunda*.

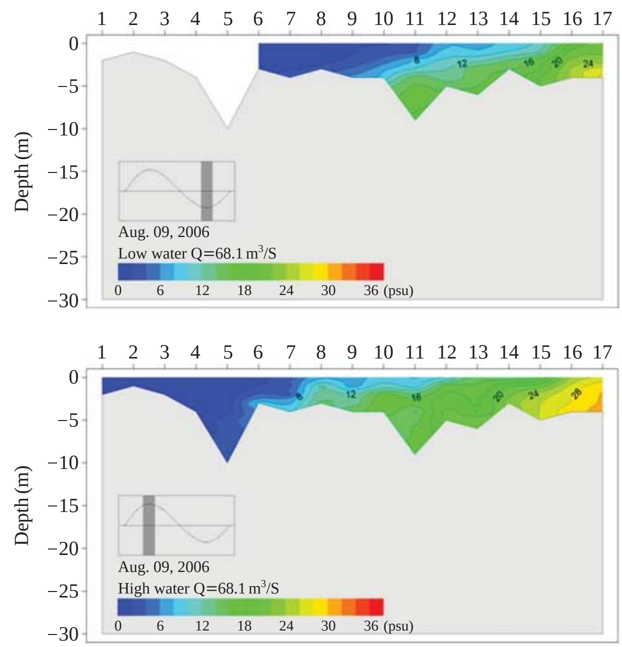

Fig. 2. Salinity ranges of in (a) low tide (upper) and (b) high tide (lower) of the Seomjin River estuary.

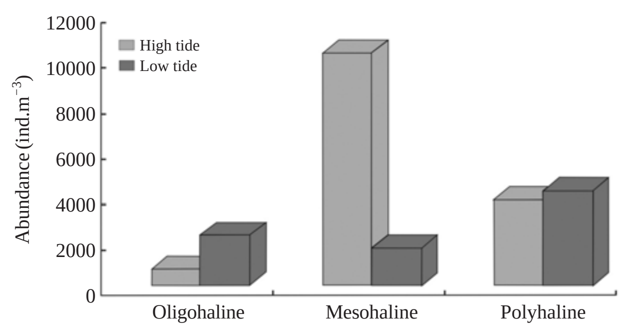

Fig. 3. Abundance of copepods (ind.m^{-3}) in high and low tides according to salinity divisions; e.g. Oligohaline (<5), Mesohaline (5∼18) and Polyhaline (>18).

Copepod movement patterns were affected by salinity ranges in estuary zones and their highest density was shown to be polyhaline, which migrated gradually from mesohaline to oligohaline zones. The highest density was observed in mesohaline zone at high tide, while in contrast the lowest density was observed in mesohaline zone at low tide (Fig. 3).

The density of oligohaline species (*Pseudodiaptomus koreanus*, *Tortanus dextrilobatus*, and *Sinocalanus tenellus*) was high in the low salinity estuarine zone during flood/low tides. However, the density of *Tortanus dextrilobatus* was

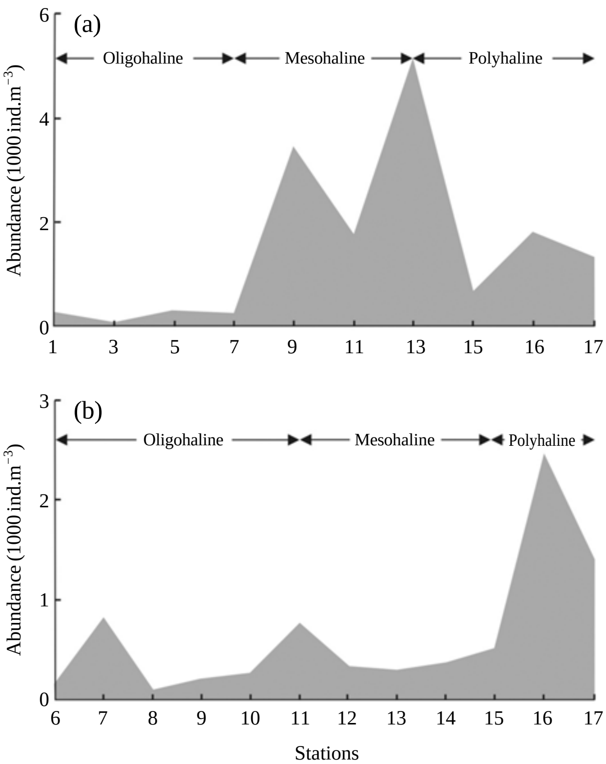

Fig. 4. Variation of copepods abundance (ind.m^{-3}) at difference sampling stations in, (a) high tide/flood and (b) low tide/ebb of the Seomjin River estuary.

high at ebb/high tides in the mesohaline zone. Although oligohaline copepods varied highly in density within different salinity zones and sampling locations, their density was widely distributed during ebb tides. During both tides, the densities of *Pseudodiaptomus koreanus*, *Tortanus dextrilobatus*, and *Sinocalanus tenellus* were highest in low salinity areas, followed by high salinity areas. However, the density of a few *Pseudodiaptomus koreanus* was somewhat higher in polyhaline zones which indicated that it is a highly diversified and retentive species. *Tortanus dextrilobatus* and *Sinocalanus tenellus* density was highest in oligohaline and mesohaline areas. Low density was also estimated in polyhaline zones (Figs. 4 and 5). The density of mesohaline species (*Acartia ohtsukai* and *Acartia forticrusa*) was usually high at the mesohaline zones. The density of *Acartia ohtsukai* was also found to be highest in the polyhaline and mesohaline areas, but the density of *Acartia forticrusa* was zero at polyhaline while few copepods were found in the oligohaline zone. They are widely distributed in the mesohaline zone (Figs. 4 and 5).

The densities of polyhaline species (*Calanus sinicus*, *Paracalanus parvus* s. l., *Labidocera rotunda* and *Centropages dorsipinatus*) were high in polyhaline areas while low in oligohaline areas during low tide (Fig. 4). During high tide, the density of *Calanus sinicus*, *Paracalanus parvus* s. l and *Labidocera rotunda* were highest in the polyhaline region, but the density of *Centropages dorsispinatus* was highest in the mesohaline region. This group of copepods were not observed in the oligohaline division but occasionally a few of them were found in this salinity range because of environmental factors (Figs. 4 and 5).

Overall copepod density varied between low and high tides with salinity; in high tide, the highest density was observed at mesohaline station 13 (5,113 ind.m^{-3}) and the lowest was observed at oligohaline station 3 (56 ind.m^{-3}) (Fig. 4a). On the other hand, at low tide the highest density of copepods was at polyhaline station 16 (2,457 ind.m^{-3}) and the lowest was at oligohaline station 8 (85 ind.m^{-3}) (Fig. 4b). The present result showed significant difference in density with different tides ($p < 0.05$).

On the other hand, in high tide *Pseudodiaptomus koreanus*, *Tortanus dextrilobatus*, *Paracalanus parvus* s. l. showed significant difference in their densities between stations ($p < 0.05$), while *Acartia ohtsukai* was insignificant ($p > 0.05$). In low tide, *Pseudodiaptomus koreanus*, *Tortanus dextrilobatus*, *Acartia ohtsukai*, *Paracalanus parvus* s. l. were gradually dominant along high salinity gradient, but only *Pseudodiaptomus koreanus* and *Tortanus dextrilobatus* showed significant difference in their densities among stations ($p < 0.05$).

DISCUSSION

Estuarine copepods were well distributed and migrated from changing salinities in different stations. In the Seomjin River estuary, copepods display species-specific responses during high and low tides and copepods change in a particular habitat salinity zone caused by tide and salinity. Generally, estuarine copepods were dominant in their most favorable salinity zone, but they had to move to other salinity zones because of changing ecological processes. Despite of this fact, they are able to retain their density through horizontal or vertical migration strategies. Copepod populations

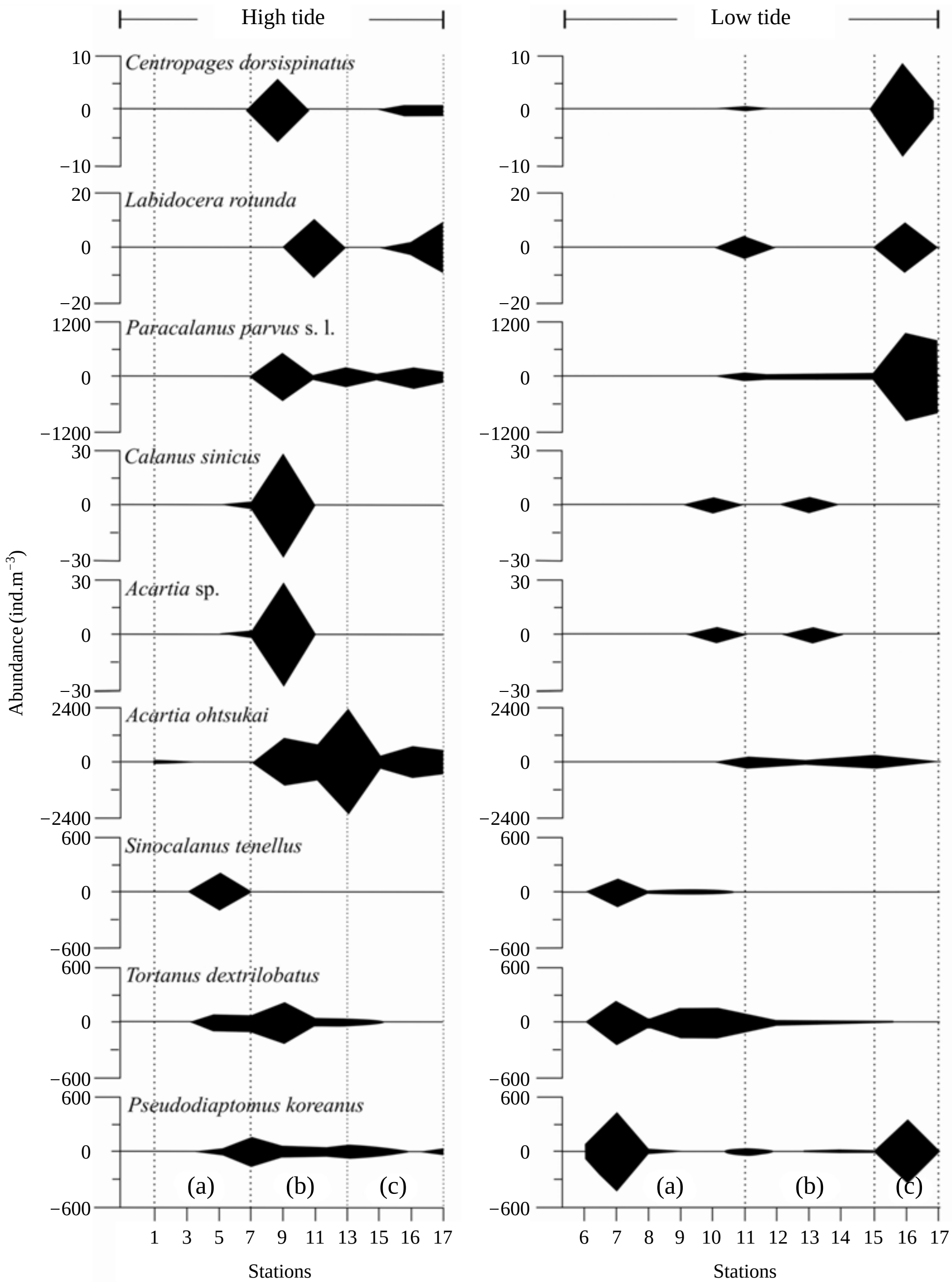

Fig. 5. Species level distribution pattern of copepods in both high tide and low tide of the Seomjin River estuary. (a, oligohaline of high/low tide; b, mesohaline of high/low tide and c, polyhaline of high/low tide.).

make significant horizontal movements within the tidal region, where different densities are shown due to the influence of tides and salinity fluctuations. Higher densities and total abundances are found at high tide than at low tide (Robertson and Dixon 1988; Wang *et al.* 1995). When a river was swollen because of heavy rainfall, water flow was much faster than usual. At that time indigenous river-estuarine zooplankton will be swept out to sea despite of such maintenance mechanisms (Ueda *et al.* 2004). The present results have shown that population abundance was highest at high tidal zones than at low tidal zones because heavy rainfall broadened the adjacent flood area out from the river basin where the copepod population was randomly highly distributed, while the concentration of copepods was reduced due to a lack of suitable environmental conditions.

In the Seomjin River estuary, high and low tide migration, which occur four times, every six hours during a lunar day. They also include discharge, heavy rainfall during August, which affects the functioning of the reservoir ecosystem. Heavy rainfall flooded adjacent areas on the river bank, which caused salinity to dramatically change and tidal movements to activate the flood tidal ecology. Flood had a clear effect on zooplankton, both in concentration and composition (Godlewska1 *et al.* 2003). The positions of the mixing zone between the two water masses within the estuary will obviously change, not only with the ebb and flood flow of the tides, but also seasonally, depending on the volume of freshwater input. For example, *Tortanus dextrilobatus* was shown to be highest in the mesohaline zone at high tide, while usually being highest at oligohaline at low tide within the Seomjin River estuary. However, during ebb tides the density increased in the mesohaline zone and decreased in the oligohaline zone. The inability of coastal species to acclimatize to varying salinity of estuarine waters may be responsible for population declines. Like this, each copepod species has its own specific salinity zone, while particular physical environmental factors directly influence population transfer.

Ueda *et al.* (2004) reported that a gorge connected to the estuary of the river was important in maintaining the population of copepod species that move from the estuary to the bottom layer of the gorge. And another migration patterns have been identified in some copepods, which showed a trend of rapid downward migration from high to low tidal phases (Schlacher and Wooldridge 1995). In the mixing process, salinity underwent large variation and the influence of this change may not only vary from species to species, but also among different development stages (Lee and Peterson 2003), and the daily and seasonal salinity variations are important factors affecting copepod life cycle in estuarine conditions (Joan 1963). In this study, the response of copepods to instantaneous changes of salinity was to increase in numbers toward the sea and decrease in numbers toward the river. Some clearly adapted, while other were clearly influenced by salinity changes. Jeffries (1967) recognized the importance of salinity in a study on copepod spatial and temporal distributions. The distribution of species that inhabit estuaries was closely related not only to salinity but also to water temperature, food, and other factors (Uye *et al.* 1982). The survival of copepodites based on salinity change was clearly lower to that of adults (Guillermo *et al.* 1999). Zooplankton species in estuaries are often individually distributed along a salinity gradient (Miller 1983; Suh *et al.* 1991; Park *et al.* 2002). When a large volume of freshwater runoff meets the sea in areas such as estuaries, salinity can vary dramatically in both the horizontal and vertical planes. Horizontal salinity gradients are very well studied and often determine the horizontal distribution and density of organisms throughout an estuary (Kinne 1966; Ambler *et al.* 1985). The variable salinity in low and high tides clearly influenced population distribution and migration. Salinity induced stress, caused by any change in salinity from ambient (Kinne 1966) and tended to move in a particular area.

ACKNOWLEDGEMENTS

We would like to thank the biodiversity laboratory members at Chonnam National University for their assistance with sample collection.

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Received: 25 September 2012
Revised: 5 June 2013
Revision accepted: 6 June 2013