The Field Observations on the Littoral Swarming of Cladocera (*Scapholeberis kingi* Sars 1903) and the Correlation with Environmental Factors

La, Geung-Hwan, Hyun-Gi Jeong, Myoung-Chul Kim,
Hyun-Woo Kim[1] and Gea-Jae Joo*

(Department of Biology, Pusan National University, Busan 609-735, Korea
[1]Department of Environmental Education, Sunchon National University,
Suncheon 540-742, Korea)

Swarm formation of *Scapholeberis kingi* Sars 1903 was observed in a shallow reservoir on 27 May 2007 (Dongpan Reservoir) for the first time. Dense swarms composed of asexual females, only occurred during daytime (13:00-17:00, local time) at the littoral zone. Correlation between density of *S. kingi* and environmental factors such as water temperature and density of juvenile fish were positively significant. Therefore, it is suggested that the swarming of *S. kingi* seems to be induced for predator avoidance than increase of mating chance, and water temperature may affect their swarming behavior.

Key words : Swarming, *Scapholeberis kingi*, juvenile fish, environmental factors

In natural food web, preys interact with various predators and these communications drive the evolution of prey's survivor strategies. One of the anti-predator strategies, synchronization of the spatiotemporal distribution (aggregation or swarming) is well-known phenomenon in the terrestrial insects, birds and certain mammals. In aquatic environments, not only the vertebrate such as fish (Pitcher, 1986) but also free-living zooplankton builds up the swarms.

Cladocerans are the worldwide spread filter feeders (except some raptorial species) which ingest mainly phytoplankton and bacteria (DeMott, 1982; Riccardi, 2002) and transfer energy to the higher level such as fish in the food web (Confer and Blades, 1975). Among the cladoceran, several species are known to form swarms. As well as the induction of patchy distribution in laboratory condition (Jensen and Jakobsen, 1999), swarming of *Daphnia pulex*, *D. magna*, *Ceriodaphnia affinis*, *Holopedium gibberum*, *Moina affinis* and *Moina* sp. have been observed in many natural habitats (Brandl and Fernando, 1971; Johnson and Chua, 1973; Ratzlaff, 1974; Tessier, 1980; Kvam and Kleiven, 1995; Mitchell *et al.*, 1995).

In general, ultimate purpose of swarm formation seems to be predator avoidance. It is obvious that the encounter rate is lower when preys aggregated than dispersed, thus swarm has predator avoidance effect. Moreover, predators hesitate when they attack swarm of preys (Allen, 1920). There is a dilution effect; one particular prey has a relatively low risk to be selected by predator when in the larger swarm (Foster and Treherne, 1981). Effect of aggregation depends on the number of participants (Neill and Cullen, 1974) and density (Milinski, 1977).

In addition to the direct effect of the predator presence on the swarm formation, environmental factors affect swarm formation. Low food condition showed a negative effect on dense distribution of *Daphnia* and *Bosmina* (Jakobsen and John-

sen, 1988; Jensen and Jakobsen, 1999). Diel vertical migration of *Daphnia* is also based on the ability of food detection (Johnsen and Jakobsen, 1987). Turbidity of the water column may affect behavioral response of cladoceran, although high turbidity inhibits appearance of *Daphnia spinulata*, *Moina micrura* prefers turbid environment with abundant suspended solids (Gabellone *et al.*, 2001). Work and Gophen (1999) demonstrated laboratory induced high turbidity decreased reproduction and moulting rates in *Daphnia lumholtzi*.

From field surveys, we found swarms of cladoceran *Scapholeberis kingi* newly in a small reservoir, described their density and diel pattern of swarms. In addition, changes of cladoceran community and physico-chemical factors such as water temperature, pH, DO and turbidity as well as chlorophyll *a* and density of juvenile fish were estimated. Then, by the correlation analysis of density of *S. kingi* and all parameters, we determined swarm-inducing factors.

Field sample collections were conducted in the Dongpan Reservoir (N: 35° 18′8.28″, E: 128° 41′ 11.9″, Changwon City) from 27 to 28 May 2007. The Dongpan Reservoir is shallow (maximum depth, ca 2 m) and has an area of 2.42 km². Five sampling sites were selected parallel to the littoral zone of the reservoir and the water depth was less than 10 cm. In the sampling sites, aquatic plants such as *Acorus calamus*, *Pseudoraphis ukishiba* and *Trapa japonica* were inhabited. The distance between each site was 2 m to minimize disturbance from the continuous sampling. In order to evaluate the changes of cladoceran abundance in the sampling sites, 2 hours interval samplings were conducted through 24 hours (total 12 samplings). Surface water (500 mL) was collected and filtered with 30 μm plankton net to make concentrated samples. Then the samples were fixed with sucrose-formalin to prevent distortion of carapace and loss of eggs or neonates from the brood chamber of an adult cladoceran female (Haney and Hall, 1972) which can cause overestimation of the enumeration. The final volumes of the samples were adjusted to 50 mL. To examine the density of cladocerans, 1 mL was counted with a microscope (Carl Zeiss Axioskop 40) at the × 20 magnification and rotifers not included in the counting. During the counting, the sex composition of each species and the number of sexual females that have ephippium was
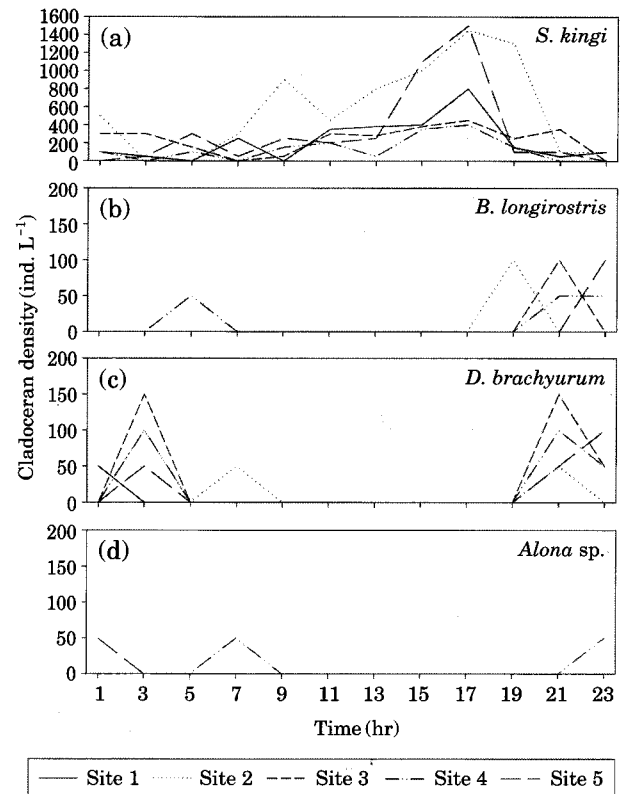

Fig. 1. Diel changes of cladoceran densities at 5 sites.

observed. Basic limnological parameters such as water temperature, pH, DO, turbidity and chlorophyll *a* of the sampling sites were measured in situ using multi-parameter water quality monitors (YSI 6600). Density of juvenile fish was estimated with a dip net (20 cm × 15 cm, 500 μm mesh). Shoreward filtering (1 m distance, 10 replicates) at each site with an interval of 4 hours was conducted and juvenile fishes were counted after the formalin preservation. Correlation analysis of diel changes of cladoceran density and environmental factors was conducted with SPSS 12.0.

At the 5 sampling sites, cladoceran community was comprised 4 species including *Scapholeberis kingi*, *Bosmina longirostris*, *Diaphanosoma brachyurum* and *Alona* sp. Among these cladocerans, the most dominant species was *S. kingi*. At all sites, density of *S. kingi* began to increase at 13:00, reached maximum at 17:00 local time (1,500 ind.L^{-1} at site 5) and showed fluctuations (9:00 at site 2). After the sunset, their density decreased rapidly to that of sunrise (Fig. 1a). Although the relatively high densities were main-
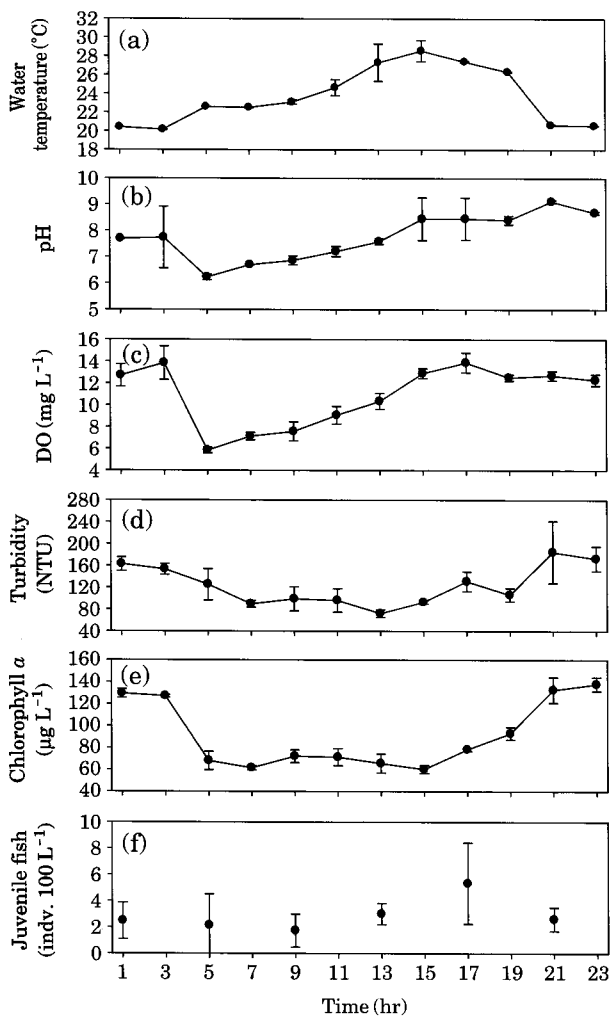
Fig. 2. The changes of environmental factors (Lines indicate average value of the 5 sites).

Table 1. The correlation between density of *S. kingi* and environmental factors (n=12) and juvenile fish density (n=6).

Environmental factors		Site				
		1	2	3	4	5
Water temperature (°C)	r	0.783	0.819	0.417	0.645	0.729
	p	0.006	0.001	0.177	0.024	0.007
pH	r	0.193	0.356	0.416	0.085	0.179
	p	0.548	0.257	0.178	0.792	0.578
DO (mg L^{-1})	r	0.307	0.297	0.589	0.341	0.335
	p	0.333	0.349	0.044	0.278	0.287
Turbidity (NTU)	r	−0.189	−0.409	0.025	−0.283	−0.211
	p	0.557	0.187	0.938	0.457	0.510
Chlorophyll *a* (μg L^{-1})	r	−0.442	−0.391	0.027	−0.491	−0.442
	p	0.150	0.209	0.934	0.105	0.150
Juvenile fish density (ind. 100 L^{-1})	r	0.797	0.754	0.822	0.805	0.903
	p	0.057	0.083	0.045	0.053	0.014

tained from 13:00 to 19:00 at five sites, swarms of *S. kingi* were only observed during four hours (from 13:00 to 17:00). Swarms developed right under the water surface with disc shape, 4-8 cm in diameter. Swarm formation was also occurred at the out side of sampling sites along the littoral zone of the reservoir. Ventral side of *S. kingi* often exposed through the water surface and they drift horizontally. *D. brachyurum, B. longirostris* and *Alona* sp. appeared occasionally; overall, they appeared at night (Fig. 1b, c and d) and showed periodicity. Each species was composed of asexual females exclusively.

Water temperatures of the nighttime were around 20°C during 21:00-03:00. Daytime water temperatures began to increase at 05:00 and rea-

ched 28.6°C (15:00, average of 5 sites), then rapidly declined to 20.6°C (21:00). The steepest decline (5.7°C) was observed between 19:00 and 21:00 (Fig. 2a). pH and DO concentration showed similar patterns. Averages of five sites were lowest at 05:00 (6.2 and 5.9 mg L^{-1} respectively), gradually increased during daytime, however, the maximum values were observed at 21:00 and 17:00 (9.1 and 13.3 mg L^{-1} respectively) (Fig. 2b and c). Although it fluctuated within time and site, turbidity of water column was relatively low during 07:00-15:00, ranged 72.3 NTU-98.9 NTU. Sharp increase of turbidity occurred at 17:00 (130.9 NTU) and prolonged until dawn (05:00, 125.2 NTU) (Fig. 2d). Overall, concentration of chlorophyll *a* was high during night time (21:00-03:00, mean 131.8 μg L^{-1}) and maintained almost half level until evening (05:00-19:00, mean 71.3 μg L^{-1}) (Fig. 2e). Density of juvenile fish was relatively high at site 4 and site 5. At these sites, their density was highest at 17:00 (8.0 and 9.3 ind.100 L^{-1} respectively). Overall, daytime density was higher than that of nigh time (Fig. 2f). Sizes of juvenile fish were ca. 2-3 cm mainly and *Pseudorasbora parva* was dominant species. *Micropterus salmoides, Carassius auratus* and *Pseudobagrus fulvidraco* were also observed.

From the results of statistical analysis (Pearson Correlation Coefficient), interrelationships were found in density of *S. kingi* between water tem-

perature and juvenile fish density. Water temperature showed positive relationship at all sites with significance except site 3 (p=0.177). Juvenile fish density also had positive relationships, however, significance was found only at site 3 (r=0.822, p=0.045) and site 5 (r=0.903, p=0.014) and the other sites showed marginal. In general, pH and DO as well turbidity and chlorophyll a had a positive or negative relationship but these environmental factors were not significant (Table 1).

Swarming behavior provides an advantage in survivorship by confusion effect (Allen, 1920) and group vigilance (Bertram, 1980). On the other hand, there are costs due to the overexploitation of food source within swarms (Tessier, 1980; Jakobsen and Johnsen, 1988) and unintended attraction of fish, which detects electrical noise of swarms (Freund et al., 2002). D. pulex persists to aggregate even in a total darkness (Kleiven et al., 1996) and this reaction is effective against tactile predators such as night hunting Chaoborus (Kvam and Kleiven, 1995). Our observations on the swarm of S. kingi showed diel patterns; swarm formation occurred only at daytime and dispersed at night. Therefore, swarming of S. kingi may be adapted to visual predators primarily. Young (1978) showed one of the proximal purpose of swarming in cladoceran (D. magna) is mating with relatively high encounter rate when both sexes are within the swarm. Thus, it is suggested that the major motivation of swarming is predator avoidance since swarms of S. kingi were composed of only asexual females. In addition, water temperature also may affect swarm behavior of newly observed swarm-forming S. kingi.

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