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Distribution of Zooplankton in Asan Bay, Korea with Comments on Vertical Migration

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아산만 동물플랑크톤 분포와 수직이동

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Seasonal distributions of zooplankton were investigated in Asan Bay, Korea. *Labidocera euchaeta, Sagitta crassa, Calanus sinicus, Acartia omorii* were dominant taxa throughout the year with seasonally varying percent compositions. Bivalve veliger larva (fall), Decapoda larva (spring and summer), and *Paracalanus parvus, Evadne tergestina* (summer) were also dominated during centain period. The patterns of time dependent vertical distributions of one major taxon, *A. omorii,* showed seasonal differences, i.e., it showed the trends of normal vertical migration in winter and reversed vertical migration in spring. At surface layer day time abundances were equal or less than night time abundances in general.

Introduction

Many previous studies on zooplankton distribution in the coastal areas and bays of Korea showed seasonal fluctuations in species composition and abundances(Choe, 1972; Lee, 1972; Shim and Ro, 1982; Kim and Huh, 1983; Kang, 1986; Choi et al., 1988; Shim and Yun, 1990). But no study has been done in Asan Bay. The only zooplankton study in this bay was on the sampling scheme by Park(1990). Along with the day-night difference in catches, he showed that some major species of zooplankton migrated vertically even in this shallow area of strong tidal mixing.

Present study was initiated to use to long term data of zooplankton distribution for the monitoring purpose in Asan Bay, where construction of many industrial complexes and reclamation were under way so that monitoring the possible environmental changes was to be needed. As a first step, we report the seasonal variation in species composition and abundance of zooplankton in this bay. Also, we examined whether the vertical distribution patterns shown in Park(1990) was invariant with season. However, the causes of the distributional patterns shown in this study are not discussed. It is because multidisciplinary approach that includes the studies on physical oceanography and phytoplankton, which

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is under way, is essential for that.

Materials and Methods

Zooplankton samples were collected at about 3 *km* east of Ibpado(37° 06′ N and 126° 34′ E) located in Asan Bay for one day and night in each season. Fall, winter, spring, and summer samples were collected during November 11~12, 1989, February 27~28, May 26~27, and August 5~6, 1990, respectively.

An open/closing "Bongo" net(mouth diameter 60 *cm*) fitted with 0.333 and 0.505 *mm* mesh size nets on each side was used. The net was towed obliquely at depths of 0~5 and 5~10 *m* during day and night(water depth, about 15 *m*). The time lag between the day sampling and night sampling was kept to be about 12.5 hours to make the tidal phase be as equal as possible so that the distance between the centers of the moving water parcels sampled during the day and night was minimized. It was not only because the day-night difference, if any, could be interpreted in terms of locality unless the same water mass was sampled, but also because it was practically difficult to deploy a marker buoy in this bay of shallow and strong tidal mixing. The effort for the sampling of same water mass was shown to be effective in this area(Park, 1990). The period around dusk was avoided to minimize variation due to the vertical migration if any.

Tow speed and duration were about 1 *m/sec* and 7~8 minutes, respectively. The volume filtered during towing was calculated with the flow meter attached to the net. Three replicate samples were intended for each time and depth interval. Samples were fixed with buffered formalin.

A Folsom Plankton Splitter was used to split the samples into subsamples of countable size. Each subsample containing about 500~1,000 individuals by subsampling was counted under a dissecting microscope with identification to lowest practical taxon.

The differences in abundances with regard to sampled layers and sampling time were examined by partitioning the variances into sampling time effect, sampled layer effect, and interaction of these two effects. That is, analysis of variance(ANOVA) with the same model in Park(1990) was done with abundance data. In this ANOVA, significance of the interaction was major concern since significant interaction could be interpreted as minimum requirement for the indication of the presence of vertical migration as explained by Park(1990). When interaction was not significant, this term was deleted from the model for the test of significant difference between the sampling time and/or sampled layer.

Results

From the total of 94 samples(49 from 0.333 *mm* mesh net and 45 from 0.505 *mm* mesh net), 56 taxa were identified. *Noctiluca scintilans* was not included not only because of its large variation in abundances caused by the clogging effect of the net but also because of its controversial taxonomic position, Dinoflagellate. The list and seasonal average abundances, weighted mean of the two layer sampled and two sampling time, were given in Appendix I.

The numbers of taxa appeared in each season were given in Table 1 with the number of replicate samples in parentheses by sampling time and sampled layer. Total number of taxa appeared was the greatest in fall, sharply reduced during winter, and then gradually increased with seasonal warming. However, total abundance(individuals/m^3) was the smallest in fall and the greatest in summer. This relation was shown in Figure 1.

The numbers of taxa appeared at different time or at different depth range did not show noticible seasonal patterns. In addition, mesh size of the net did not seem to affect significantly on the numbers of the taxa appeared though samples from the smaller mesh net usually yielded a few more taxonimic groups. But, the rank orders of abundances were usually not in good agreement between the samples from the two different mesh size nets. As expected, and as shown in Table 2, the abundance of the larger animals showed higher ranks in the net of large mesh.

Table 1. Number of zooplankton taxa observed in Asan study with the number of replicate samples in parenthesis.

		Fall		Winter		Spring		Summer	
		333*μm*	505*μm*	333*μm*	505*μm*	333*μm*	505*μm*	333*μm*	505*μm*
Day	surface	29 (4)	30 (4)	17 (3)	10 (2)	24 (3)	13 (3)	32 (3)	29 (2)
	mid-stratum	31 (5)	27 (3)	13 (1)	13 (3)	21 (3)	18 (3)	31 (3)	28 (3)
Night	surface	31 (3)	24 (2)	17 (5)	15 (5)	24 (3)	19 (2)	33 (3)	27 (3)
	mid-stratum	28 (2)	22 (1)	16 (3)	10 (3)	25 (2)	21 (3)	32 (3)	32 (3)
Total		41	37	23	17	28	25	38	36

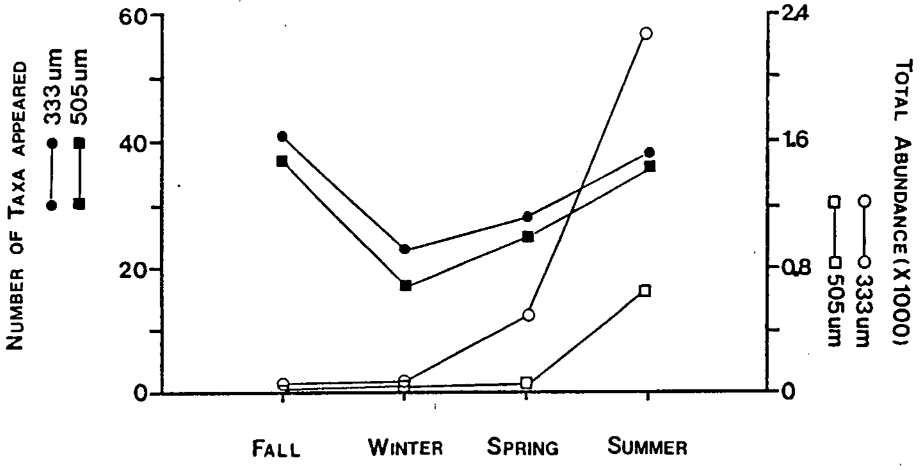

Fig. 1. Number of taxa appeared and total abundance(individuals/m^3) of zooplankton in the study area.

The percent compositions of dominant taxa are given in Figure 2. In this figure the taxa of which percent compositions were less than 5% were all included in 'etc.'. As shown in the figure, dominant groups have been changed as season changed in both sets of samples of different mesh size nets.

In the samples from 0.333 *mm* mesh net, *Labidocera euchaeta*(35.5%), *Sagitta crassa*(19.2%), bivalve veliger larvae(19.2%) were the dominant groups during fall. During winter, *Acartia omorii* (47.8%) was predominant with *Labidocera euchaeta* (24.5%) and *Calanus sinicus*(13.0%). The percent composition of *A. omorii* was increased up to 68.0% in spring. The species composition was dramatically changed in summer with dominant groups, *Paracalanus parvus*(*P. indicus*, 30.1%), and sharply increased decapoda larva(18.0%). *Evadne tergestina* (14.2%) appeared only during summer, and *A. omorii* was replaced by *A. pacifica*(9.1%) in this season.

As mentioned above, samples from the net of 0.505 *mm* mesh showed different percentage composition comparing with those from the net of 0.333 *mm* mesh. Proportions of *C. sinicus* were bigger in the samples from the net of 0.505 *mm* mesh except during summer while the proportions of *A. omorii*, one of the dominat species in this bay, were much smaller. Proportions of *C. sinicus* were 5.7% (fall), 30.8% (winter), 25.9% (spring) and 0.5% (summer). Proportions of *A. omorii* were less than 1% during fall, winter, and summer, and 5.1% in spring.

The major groups with a criterion of more than

Table 2. Rank orders of abundances of the major taxa of zooplankton obtained from 333μm and 505 (in parenthesis) μm mesh net in fall of 1989.

Taxon	Day(0~5m)	Day(5~10m)	Night(0~5m)	Night(5~10m)
Labidocera euchaeta	3 (1)	3 (2)	1 (1)	1 (1)
Sagitta crassa	2 (2)	2 (1)	3 (2)	2 (2)
Bivalve veliger larva	1 (3)	1 (8)	2 (12)	3 (12)
Paracalanus parvus	4 (6)	4 (13)	4 (13)	5 (14)
Calanus sinicus	12 (11)	9 (4)	5 (3)	4 (3)
Corycaeus spp.	5 (7)	5 (14)	7 (13)	6 (12)
Acartia omorii	6 (12)	7 (15)	6 (13)	11 (14)
Mysidacea	11 (13)	12 (9)	8 (4)	7 (4)
Tortanus forcipatus	7 (8)	6 (11)	9 (11)	8 (9)
S. enflata	9 (4)	8 (3)	10 (6)	12 (6)
Decapoda larva	8 (5)	11 (5)	11 (5)	10 (7)
Calanopia thompsoni	14 (15)	15 (11)	12 (7)	9 (5)
Siphonophora	13 (9)	14 (10)	13 (10)	13 (8)
T. spinicaudatus	10 (10)	10 (6)	15 (8)	15 (11)
Liriope tetraphylla	15 (14)	13 (7)	14 (9)	14 (9)
p value for the test of H_0: same order between 333μm and 505μm net samples	0.0018	0.3156	0.5634	0.0999

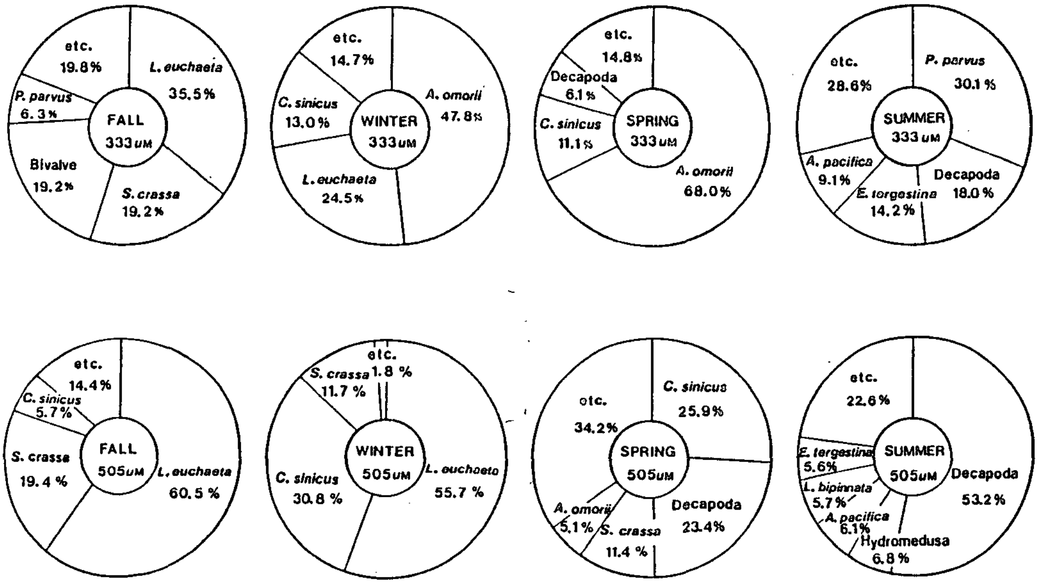

Fig. 2. Percent composition of zooplankton in the study area obtained with two different mesh size nets.

10% composition from either of 0.333 and 0.505 *mm* mesh nets could be summarized as in Table 3.

Vertical stratification of abundances with relation to season and sampling time was examined for the 5 taxa of which abundances were always greater than $1/m^3$(samples from the net of 0.333 *mm* mesh only) by ANOVA. They were *P. parvus, A. omorii, C. sinicus, S. crassa* and *L. euchaeta.* The assumptions and the rationale for the use of this method are given in Park(1990). Comparisons of abundances between the sampled depths at day and night were done for suppliment. The results are summarized in Table 4.

During fall and summer none of these five taxa showed significant interactions. That is, no evidence of vertical migration was found with the given data. In every case, but one(Summer; *S. crassa*), day time abundances were equal or less than night time abundances in upper 10 *m* depth layer. In summer, *S. crassa* showed high abundance during day time.

Table 3. Major taxa of zooplankton in Asan Bay, Korea.

Taxon	Fall	Winter	Spring	Summer
Labidocera euchaeta	***********	*****		
Sagitta crassa	***********	***********	********	
Bivalve Larvae	*******			
Acartia omorii		***********	************	
Calanus sinicus		***********	************	
Decapoda Larvae			*************	************
Paracalanus parvus				************
Evadne tergestina				************

Table 4. Summary of ANOVA results. Abbreviations are explained below.

	P. parvus	*A. omorii*	*C. sinicus*	*S. crassa*	*L. euchaeta*
Fall	No Int. D = N S = M	No Int. D = N S = M	No Int. D < N S = M	No Int. D < N S = M	No Int. D > N S = M
Winter	No Int. D = N S = M	Sig. Int. D: S < M N: S > M	Sig. Int. D: S < M N: S > M	Sig. Int. D: S < M N: S > M	Sig. Int. D: S < M N: S > M
Spring	Sig. Int. D: S < M N: S > M	sig. Int. D: S > M N: S < M	No Int. D = N S < M	No Int. D = N S = M	No Int. D = N S < M
Summer	No Int. D = N S = M	No Int. D = N S = M	No Int. D = N S = M	No Int. D > N S = M	No Int. D = N S = M

abbreviations: No Int.; No significant interaction of sampling time and sampled depth at $\alpha=0.05$ level.
Sig. Int.; Significant interaction at $\alpha=0.05$ level.
D, N, S, M; abundances at day time, night time, 0~5*m* layer, 5~10*m* layer, respectively.
<, >, =; significantly less, more abundant and no significant difference at $\alpha=0.05$ level, respectively.
D:, N:; Day and night time, respectively.

In winter, all taxa but *P. parvus* showed significant interaction, and abundance at surface layer was always less than that in mid-depth layer during day time.

P. parvus and *A. omorii* showed significant interactions in spring while the other three taxa did not. *A. omorii* was the only taxon that showed significant interaction during the consecutive two seasons. But the patterns were different in each season. Day time abundance at surface layer was significantly less than that in mid-depth layer in winter, but it was reversed in spring. Time dependent vertical distribution of *A. omorii* was drawn in Figure 3, which also shows seasonal different pattern of vertical migration. Although the vertical migration pattern in summer looks similar with that of spring, there is no significant interaction between the sampled depths at day and night in summer as shown in Table 4. This suggests that this species does normal vertical migration in winter and reversed vertical migration in spring.

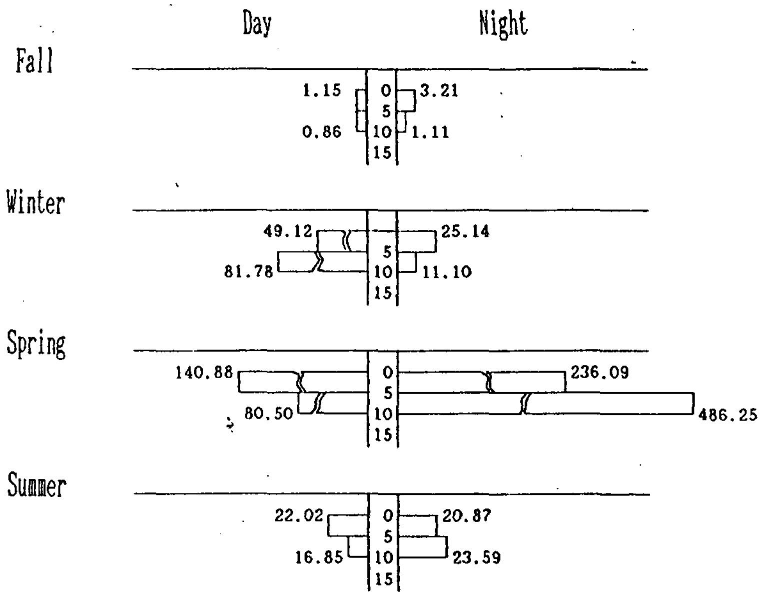

Fig. 3. Vertical profile of abundances(individuals/m^3) of *Acartia omorii* in the study area with arbitrary scale but real numbers.

Discussion

While major taxonomic groups appeared in Asan Bay were qualitatively about the same with the results of the previous studies conducted in Korean waters, the abundances were not comparable due to the differences in sampling schemes(as shown in Table 1 of Park(1990)). The differences between the two subsets of data of this study, i.e. data from the net of 0.333 *mm* mesh vs. those from the net of 0.505 *mm* mesh, support the idea that data on zooplankton distribution can not be equally compared as long as the sampling methods are different. Also, this indicates the need for a standard sampling method for the effective use of the data on zooplankton distribution.

Both the number of the taxa appeared and the abundance were minimum during the winter when sea water temperature was the lowest(Table 5). Then both increased as season changed. Abundance was the maximum in summer while the number of taxa appeared was the largest in fall. Considering the water temperatures, typical of temperate seas(Table 5), this fluctuation seems to be related with the fluctuation in phytoplankton distribution which is in turn affected by light and water temperature(Raymont, 1980). However, we do not intend to interpret the causal mechanisms for this fluctuation as mentioned in introduction.

Park(1990) indicated that some groups might do diel vertical migration even in this shallow area of active tidal mixing assuming the same water mass was sampled during day and night. Similar results were shown in this study. But the pattern was not consistent among the seasons in the case of *A. omorii.* This taxon showed evidence of normal vertical migration pattern in winter but reversed pattern in spring(Table 4). Park *et al.*(1989) showed reversed diel vertical migration of *A. tonsa* in the coastal area off Louisiana and suggested that the patterns of vertical migration might not be fixed. This non-fixed but rather dynamic diel vertical migration was also reported in other recent researches(Ohman, 1990; Forsyth *et al.,* 1990). This varying or changing patterns in vertical migration among the taxa or within a taxon indicate that the causative mechanism for the diel vertical migration can not be soly explained by physical factors such as light(Wang and Lie, 1989) or geotaxis(Raymont, 1983). Instead, it may indicated that biological interactions such as competition for the food play a far more important role for the observed diel vertical migration. That is, *A. omorii* may experience different competitional sequences as the food concentration and components of zooplankton community change with season. It is because the modes of fluctuations of the physical factors are rather fixed than variable. Hansson *et al.*(1990) also showed this in Baltic coastal area. However, more studies with multidisciplinary approaches are needed for the detailed explanation on the causal mechanisms for the different patterns of vertical migration and the biological interactions therein.

Table 5. Seasonal variation of surface water temperature and salinity in Asan Bay.

	Fall	Winter	Spring	Summer
Temperature (℃)	13.45	4.21	14.48	25.00
Salinity (‰)	30.36	30.63	30.68	

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APPENDIX I

Average abundances(individuals/m^3) of zooplankton in Asan Bay obtained by two different mesh size nets.

Taxon	Fall		Winter		Spring		Summer	
	333μm	505μm	333μm	505μm	333μm	505μm	333μm	505μm
Liriope tetraphylla	<<1	<<1						<<1
Obelia spp.					1.2	1.1	1.1	<<1
Hydromedusa	<<1	<<1	<<1	<<1	3.1	1.6	39.9	44.2
Diphyes spp.	<<1	<<1					2.4	<<1
Muggiaea spp.	<<1	<<1					5.4	2.2
Siphonophora	<<1	<<1					1.1	1.3
Actinotroch larva	<<1	<<1					1.1	1.3
Actinotroch larva			<<1		<<1		<<1	<<1
Brachiopods larva							9.6	1.0
Gastropoda	<<1	<<1			2.4	1.0	26.2	4.0
Bivalve veliger larva	12.4	0.7	<<1	<<1	2.4	<<1	9.4	<<1
Polychaeta and larva	<<1	<<1	<<1		0.5	<<1	59.5	22.5
Sagitta crassa	12.4	6.1	2.6	3.4	3.0	6.2	52.3	16.2
S. enflata	0.7	0.7						
Podon polphemoides	<<1							
Evadne tergestina							322.3	36.5
Penilia schmackeri							26.1	6.4
Conchoecia spp.		<<1			<<1			
Cirripedia nauplius	<<1		<<1		4.2	<<1	27.6	2.6
Calanus sinicus	2.8	1.8	8.8	9.1	55.3	14.2	10.5	3.3
Paracalanus parvus	4.0	<<1	2.7		10.9	<<1	682.6	5.8
Euchaeta plana	<<1	<<1						
Scolecithrix nicobanica	<<1							
Temora discaudata			<<1					
T. Stylifera	<<1							
Eurytemora pacifica					5.1	<<1		
Centropages abdominalis			<<1	<<1	21.8	1.4		
C. tenuiremis	<<1	<<1					44.8	15.1
C. furcatus	<<1	<<1						
Sinocalanus tenellus	<<1							
Pseudodiptomus marinus	<<1	<<1	<<1				1.1	<<1
Calanop0ia thompsoni	<<1	<<1					22.0	13.2
Labidocera bipinnata	<<1	<<1			<<1	<<1	54.0	37.1
L. euchaeta	22.9	18.9	16.6	16.4	1.5	1.6	1.4	<<1
Pontella spinicaudata		<<1					<<1	
Pontellopsis tenuicaudata		<<1						
Acartia omorii	1.5	<<1	32.3	<<1	337.8	2.8	20.8	1.0
A. pacifica	<<1	<<1					207.1	39.6
Tortanus forcipatus	1.2	<<1			<<1	<<1	23.2	6.5
T. spinicaudatus	<<1	<<1			<<1	<<1	35.2	12.1

APPENDIX I. (continued)

Taxon	Fall		Winter		Spring		Summer	
	333μm	505μm	333μm	505μm	333μm	505μm	333μm	505μm
Oithona spp.	<<1		<<1					
Corycaeus spp.	2.0	<<1	2.0	<<1	0.9		92.0	4.8
Oncacea spp.			<<1	<<1	<<1	<<1		
Harpacticoida	<<1	<<1	1.7	<<1	<<1			
Caligoida							<<1	<<1
Stomatopoda							<<1	<<1
Mysidacea	1.0	0.6	<<1	<<1	3.2	2.3	2.6	0.7
Cumacea	<<1	<<1	<<1	<<1	<<1	<<1	<<1	
Euphausiacea	<<1	<<1	<<1	<<1				
Decapoda larva	0.6	0.6	<<1	<<1	30.1	17.7	408.5	345.1
Lucifer reynaudii	<<1	<<1					1.0	2.1
Acetes japonicus	<<1	<<1		<<1		<<1		
Ophiopluteus larva	<<1						66.8	13.2
Oikopleura spp.	<<1	<<1			4.9	0.7	<<1	
Fish larvae	<<1	<<1	<<1	<<1	0.5	<<1	8.3	9.1
Fish egg					2.9	2.7	2.4	1.6
Total	64.5	31.3	67.7	29.5	496.7	54.7	2,268.9	648.2

아산만 동물플랑크톤 분포와 수직이동

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아산만 동물 플랑크톤의 계절별 분포를 조사하였다. 년중 *Labidocera euchaeta, Sagitta crassa, Calanus sinicus, Acartia omorii* 등이 계절에 따라 다른 점유율을 보이며 주요 우점종으로 나타났고, 기타 계절에 따라 이매패 유생(가을), 십각류 유생(봄, 여름) *Paracalanus parvus, Evadne tergestina*(여름) 등이 주요 우점종에 포함되었다.

주요 우점종인 *A. omorii*는 계절에 따라 주야 수직분포가 다른 양상을 보였는데, 겨울철에는 정상적인 주야 수직이동, 봄철에는 역전된 주야 수직이동을 하는 것으로 여겨졌다. 대부분 표층에서는 야간과 비교하여 주간에 통상 같거나 적은 양의 개체수 분포를 보였다.