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Day-Night Differences in Zooplankton Catches in the Coastal Area of Active Tidal Mixing

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조류에 의한 혼합이 활발한 연안역에서의 동물 플랑크톤 채집량의 주야 차이

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For the test of zooplankton's ability to migrate vertically in the coastal area of active tidal mixing, day-night differences in zooplankton catches were examined. Some taxa such as large Copepods, My-**sids, Chaetognatha and Bivalve larva showed high abundances at surface layer at night suggesting the presence of vertical** migration even in this shallow coastal area of active tidal mixing.

Previously used methods of sampling were reviewed to find a proper sampling method in the Korean western coastal area.

조류에 의한 해수의 혼합이 활발한 연안역에서 동물 플랑크톤이 주야 수직 이동의 능력이 있는지를 파악하기 위하여 채집량의 주야 차이를 살펴보았다. 상대적으로 크기가 큰 요각류, Mysid, 모악류, 이매패 유생 등은 야간에 표층에서 많이 채집되어 주야 수직이동이 있을 가능성을 시사하고 있었다.

본 연구 결과와 과거의 방법 등을 통하여 한국 서해 연안역에서 적절한 채집방법에 대하여 살펴보았다.

INTRODUCTION

Due to the construction of many industrial complexes and reclamation, there are many places in western coastal area of Korea of which environments are to be changed. In monitoring those possible environmental changes, both physico-chemical properties such as temperature, concentration of nutrients and/or a certain heavy metal element etc. and biological properties such as zooplankton species composition and abundances in those areas can be used as indicators.

To use the long term data of zooplankton species composition and abundance distribution for the monitoring purposes, it is necessary to have a proper method of collection that can minimize the sample variability. There are many sources of variarion in zooplankton data collected by net tows (Park *et al.*, 1989). Important sources that should be considered are: (1) avoidance of the net by the zooplankters, that is related with the tow speed and size of net mouth, (2) patchy distribution of organisms, (3) clogging of the net caused by high concentration of suspended matter including phytoplankton, and (4) temporal and spatial shift of the distribution i.e. diel vertical migration.

There are some remedies for each of these

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Table 1. Summary of sampling scheme used in Korean waters in the past. N.A. Stands for not available, * indicates that it is not written in the source but assumed to be.

Source	sampler	tow type (tow speed, m/sec)	mouth size (diameter, cm)	mesh size (mm)
Park (1967)	NORPAC	vertical (N.A.)	45	0.33 and 0.1
Kim (1971, 1972)	NORPAC	vertical (N.A.)	45	0.33
Lee (1972)	NORPAC	vertical (0.5-1)	45	0.33
	Marutoku	vertical (0.5-1)	45	0.33
Park (1973)	NORPAC	vertical (1)	45	0.33
Park *et al.* (1973)	NORPAC	vertical (1)	45*	0.33*
Shim and Ro (1982)	Clarke-Bumpus	horizontal (0.75)	12.7	0.16
Shim and Park (1982)	Clarke-Bumpus	horizontal (0.75-1)	12.7	0.16
Park and Lee (1982)	NORPAC	vertical (0.5-1)	45	0.33
	Marutoku	vertical (0.5-1)	45	0.33
Kim and Huh (1983)	simple conical type	horizontal (1)	100	0.25
Shim and Lee (1986)	Gulf-V	horizontal (1)	N.A.	0.20
Kang (1986)	NORPAC	vertical (0.5-1)	45	0.33

problems. For the avoidance problem large mouth size and high tow speed are the remedies though how large and how fast are to be decided depending on the target taxa. In collecting zooplankton as a whole, over 60 cm of mouth diameter ("Bongo" net, McGowan and Brown, 1966; "MOCNESS", Wiebe *et al.*, 1976) and tow speed of about 2 knots seem to be adequate and usual (UNESCO, 1968; Jossi and Marak, 1983). It is because net size should be consonant with vessel and winch capability and higher speeds introduce variable of extrusion.

Concerning patchy distribution, Wiebe and Holland (1968) recommended long tows and Park *et al.* (1989) showed minimum tow distance for the stabilized variance of the mean in the coastal area off Louisiana. Over 140 m of tow distance was shown to be enough by them which was equivalent with about 2–3 minutes of tow with tow speed of 1.5–2 knots.

Problem of clogging of the net caused by high concentration of suspended matter, especially in the coastal area of active mixing, can be avoided when large mesh size is used. However, since large mesh size will extrude small size zooplankton, selection of the mesh size depends on the target taxa. As shown in Table 1, usually 0.333 mm mesh was used in Korean waters in the past when no specific taxon was aimed.

Remaining source of sample variability, diel vertical migration, is considered in this study. Western coastal area of Korea is characterized by shallow depth and active tidal mixing, and no study has conducted yet as to whether zooplankters do diel vertical migration in the areas of shallow and strong tidal mixing. Park *et al.* (1989) showed different patterns of diel vertical migration in the shallow coastal area off Louisiana, and recommended time dependent stratified sampling with respect to diel vertical migration. But the area of their study is totally different from Korean western coastal area in terms of tidal mixing, that is, tide in their study area was negligible. In this study, the degree of vertical migration was evaluated to determine the proper tow type.

MATERIAL AND METHODS

Asan Bay was selected as study area not only because this bay is a typical area of above mentioned characteristics (i.e., shallow and active tidal mixing) but because envirnomental monitoring work seems to be needed in this area due to the construction of many industrial complexes and reclamation. Zooplankton samples were collected at about 3 km east of Ibpado (37° 06 'N and 126° 34 'E) located in this bay for one day and night in November 11-12, 1989 using a open/closing "Bongo" net (mouth diameter 60 cm) fitted with 0.333 mm and 0.505 mm on each side. (Samples from 0.333 mm mesh were analyzed in this study.) Sampling was done during 12:00-16:20 for day and 00:40-03:00 for night to make the tidal phase be as equal as possible so that the distance between the centers of the moving water parcels sampled at day and night was minimized. The period around dusk was avoided to minimize variation due to the vertical migration if any.

The net was towed obliquely at depths of 0-5 and 5-10 m both day and night (water depth, 15-20 m). Tow speed and tow duration were about 2 knots and 7-8 minutes, respectively. Subsequent distances traveled by the net seemed to be far enough to minimize the effect of patchiness (Park *et al.*, 1989). Two to five replicate samples were obtained for each time and depth interval.

Samples were fixed and preserved with prebuffered (pH 8) formaldehyde. The final concentration of formaldehyde was about 4%.

A Folsom Plankton Splitter was used to split the samples into subsamples of countable size. Each subsample containing about 500-1000 individuals by subsampling was counted under a dissecting microscope with identification to lowest practical taxon.

The effect of sampling time and sampled depth was examined for abundant taxa of which mean abundances were greater than one individual per cubic meter by analysis of variance (ANOVA) with the model:

$$Y_{ijk}=u+a_i+b_j+(ab)_{ij}+e_{ijk}.$$

where Y_{ijk} was the abundance of a certain taxon from i^{th} sampling time, j^{th} sampled depth and k^{th} replicate tow (or its log transformation if needed), u was the overall mean, a_i was the effect of i_{th} sampling time ($i = 1, 2$; that is, day and night), b_j was the effet of j^{th} sampled depth ($j = 1, 2$; that is, 0-5 m and 5-10 m depth), $(ab)_{ij}$ was the interaction of i^{th} sampling time and j^{th} sampled depth and e_{ijk} was error associated with i^{th} sampling time, j^{th} sampled depth and k^{th} replicate tow ($k = 1, 2, \ldots 5$, depending on the number of samples). The abundance data were $\log_{10}$ transformed when common variance assumption for the ANOVA was considered to be violated. Violation of this assumption was examined by the plot of residuals against the predicted values. When abundances were less than $1/m^3$, unit volume was increased to 10 or 100 m^3 so that all $\log_{10}$ transformed data became positive numbers.

ANALYSES AND RESULTS

From the total of 14 samples (0.333 mm mesh net samples only), thirty nine taxa were identi-

Table 2. Percent composition of major taxa of zooplankton obtained from 333 um mesh net. Abundance (individuals/m^3) data are given in Fig. 1.

Taxon	Day (0-5 m)	Day (5-10 m)	Night (0-5 m)	Night (5-10 m)
Labidocera euchaeta	14.40	19.84	43.96	48.44
Sagitta crassa	23.11	25.78	14.08	18.36
Bivalve (veliger larva)	30.42	29.76	15.30	8.87
Paracalanus parvus	9.61	6.35	6.79	3.93
Calanus sinicus	0.49	0.95	5.77	7.29
Corycaeus spp.	4.75	4.51	2.32	2.19
Acartia clausi	4.33	1.86	2.85	0.98
Mysidacea	0.75	0.52	1.92	2.16
Number of samples	4	5	3	2
Number of taxa counted	30	30	31	26

Table 3. Result of analysis of variance with the log transformed abundance of *Labidocera euchaeta*.

Source of variation	Sum of square	Degree of freedom	Mean squares	F-ratio	significance level
main effect					
time	3.1443	1	3.1443	105.122	0.0000
depth	0.3420	1	0.3420	11.434	0.0070
interaction	0.1268	1	0.1268	4.238	0.0665
residual	0.2991	10	0.0299		
total	3.6752	13			

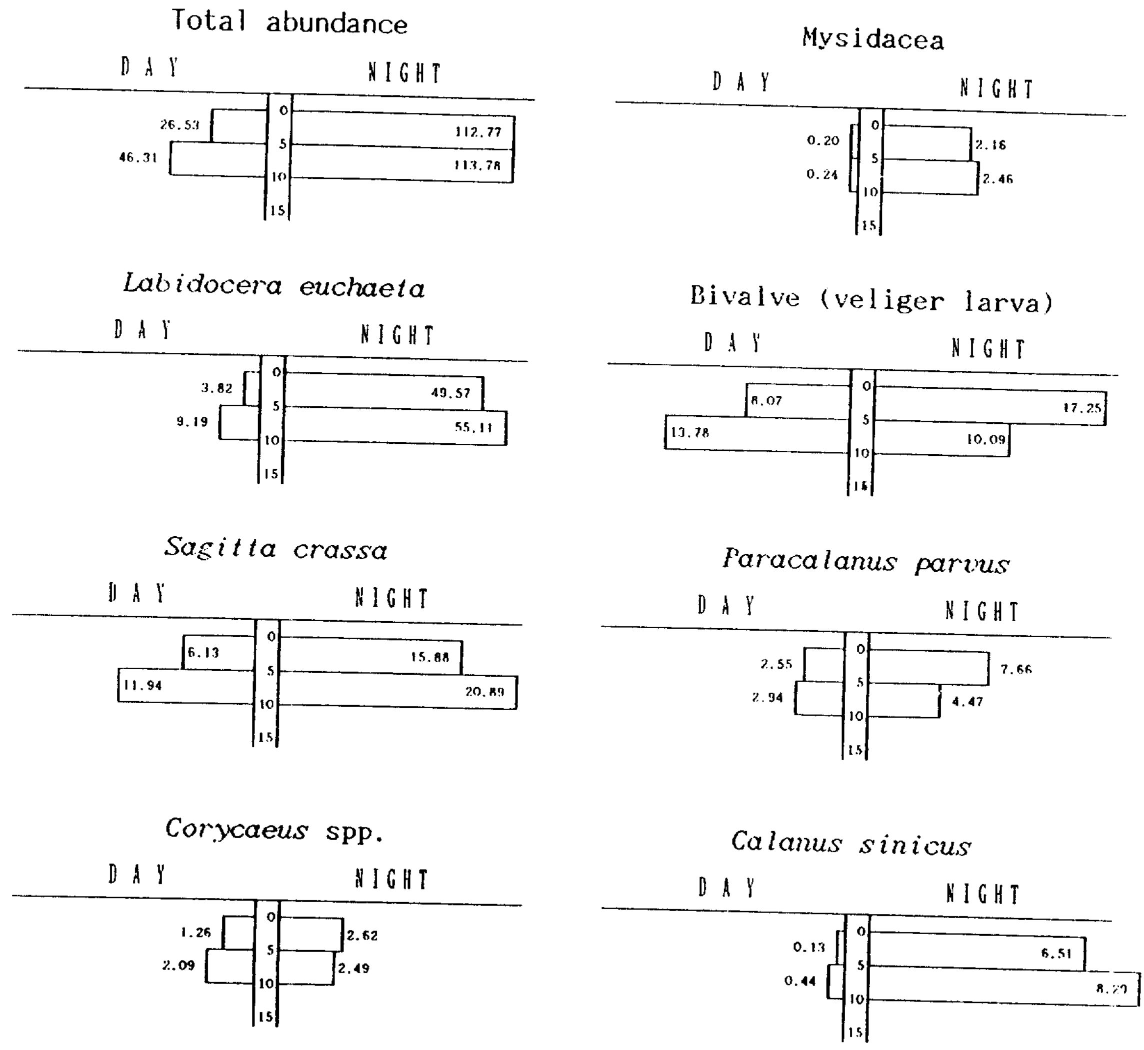
fied and counted. The number of taxa appeared in each combination of sampling time and sampled depth showed small variation (Table 2) suggesting that the effect of sampling time and sampled depth on total number of taxa appeared was negligible.

On the other hand, abundance and percent composition of major taxa were different depending on sampling time and sampled depth as shown in Fig. 1 and Table 2. Average total abundances (individuals/m^3) were 26.53 (0-5 m), 46.31 (5-10 m) during the day and 112.77 (0-5 m), 113.78 (5-10 m) at night. The abundant taxa during the day time in upper half of the water column were Bivalve veliger larva, *Sagitta crassa, Labidocera euchaeta, Paracalanus parvus* in descending order while the order of abundances was *L. euchaeta, S. crassa,* Bivale veliger larva, *Calanus sinicus* during the night. In general, night time abundance was greater than that of day time in the upper water column. In extreme case such as *C. sinicus,* night time abundance was more than ten times greater than day time abundance. This suggests that some species do vertical migration in this environment unless totally different water mass was sampled.

For the eight abundant taxa of which abundances were greater than 1/m^3, time dependent vertical distribution was examined with the results of ANOVA and vertical section of abundance distribution (Fig. 1).

Labidocera euchaeta and *Calanus sinicus*

In case of this most abundant species, *L. euchaeta,* abundance data were $\log_{10}$ transformed in ANOVA since assumption of common variance was violated. Therefore, the result must be interpreted in terms of order of abundance. As shown in Table 3, interaction effect was marginal, i.e., interaction of sampling time and sam-



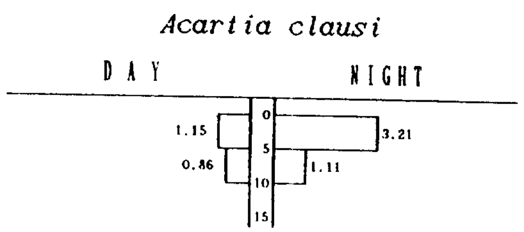


Fig. 1. Vertical sections of zooplankton abundance (number of individuals/m^3) obtained by 0.333 mm mesh net. Vertical scales for depth are in meter and horizontal scales for abundances are not same among taxa. Instead actual abundance is given at the end of each horizontal bar.

pled depth was significant at $a = 0.1$ and not significant at $a = 0.05$. This interaction term is of major concern because significant interaction can be used as a indicator of the presence of vertical migration.

If abundances are plotted against sampled depth, there will be two regression lines, one for day samples and the other for night samples, though sampled depth in this case has only two levels and is more or less qualitative. Significance of the interaction term means that the slopes of the two lines are not same so that there is one crossing point. Consequently, if abundance at depth below this crossing point is greater at day time than night time, abundance at depth above this crossing point will be greater at night time than day time in this situation, which is the indication of vertical migration under the assumption that the same water mass was sampled. (The crossing point may not be within the range of sampled depth.)

Though marginal significance of interaction term indicated that *L. euchaeta* might migrate vertically, vertical section of the abundance distribution (Fig. 1) could not support this fully. This figure shows that day time abundance was obviously smaller than night time abundance at above 10 m depth. But pattern in Fig. 1 is not sufficient to prove that this species migrates vertically. It is because abundance(s) at depths between 10 m and bottom (15-20 m) is missing. The above mentioned crossing point seems to be out side of the actual range of sampled depth in this case. "Probable" vertical migration, therefore, may be the conclusion for this species in this circumstance.

Same results were obtained for *C. sinicus*. Vertical profile of abundance distribution (Fig. 1) was the same pattern with that of *L. euchaeta* and marginal significance of the interaction term ($p = 0.1070$) in ANOVA with $\log_{10}$ transformation supported that this species might vertically migrate. Night time abundance order was significantly greater than that of day time at sampled upper layer. ("Marginal significance" for $p = 0.1070$ might not be agreeable. But considering the fact that abundance data were transformed to order of abundances, this interpretation of "possible" vertical migration based on this p value seemed to be acceptable).

Sagitta crassa and Mysidacea

Log transformed abundance data were appropriate for ANOVA in these taxa, too. In addition, vertical sections of abundances (Fig. 1) of these taxa were the same pattern as that of *L. euchaeta*. On the contrary, interaction term was not significant in these cases ($p = 0.3215$, and 0.7813, respectively). When interaction term is significant in ANOVA, testing main effect (sampling time and sampled depth in this case) may not be statistically meaningful. On the other hand, if interaction is not significant, it is better to delete this term in ANOVA model to test the main effects. When interaction term was deleted main effects of sampling time was significant in both taxa. That is, day night difference in abundance order (log transformed abundance) was significant at $a = 0.05$ level with higher abundance at night through out the sampled depth (0–10 m) in both taxa. Though the layer between 10 m to bottom was not sampled as indicated above, this significant day-night difference might indicate the presence of vertical migration like the case of *L. euchaeta*.

Bivalve (veliger larva)

Vertical distribution of this taxon (Fig. 1) showed typical pattern of normal diel vertical migration. ANOVA result also indicated that this taxon might vertically migrate. Interaction of sampling time and sampled depth on abundance (without transformation) was marginally significant ($p = 0.1065$). The crossing point mentioned above located within actually sampled depth range. So, it may be said that Bivalve veliger larva can do diel vertical migration in this active tidal mixing area.

Paracalanus parvus and *Corycaeus* spp.

The patterns of vertical distribution were similar to that of Bivalve veliger larva (Fig. 1), but presence of vertical migration was not able to be detected statistically in these taxa. In case of *P. parvus*, ANOVA was not appropriate due to the heterogeneity of residual variance whether or not abundances were $\log_{10}$ transformed. In addition, day-night difference in mean abundances was not significantly different. On the contrary, ANOVA was possible in case of *Corycaeus* spp. (without log

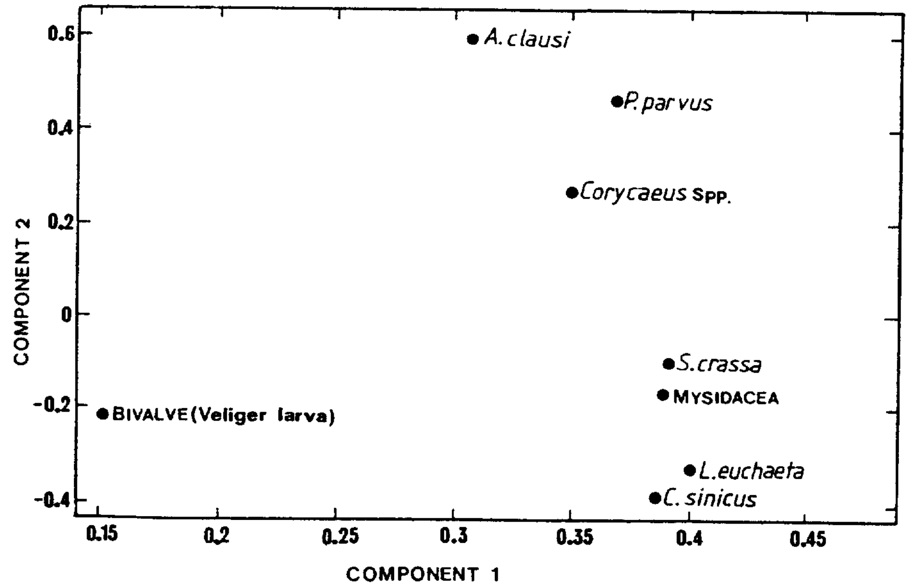


Fig. 2. Plot of first two component weights obtained by principal component analysis based on correlations of abundances.

transformation). However, neither interaction term nor the effect of sampling time was significant at $a = 0.05$ level. Possible conclusion might be no sufficient evidence of vertical migration in this case.

Acartia clausi

The situation was almost same with above mentioned two taxa. The only difference was that mean abundance was a little bigger at 0-5 m during day time. But, the difference in mean abundances between the two sampled layers was statistically meaningless because of the relatively big variance. Therefore, this species may be included in the category of above two taxa group.

In summary, the most abundant eight taxa could be grouped into three based on the patterns of time dependent vertical distribution. They were: 1) Bivalve veliger larva which was found to do vertical migration in this study area of active tidal mixing, 2) *L. euchaeta, C. sinicus, S. crassa,* and Mysidacea of which vertical migration was partially supported either by the significance of the interaction term in ANOVA or by the significant day-night difference in abundances in upper 10 m depth, and 3) *P. parvus, Corycaeus* spp. and *A. clausi* for which any evidence of vertical migration was not found.

This grouping was also supported by the principal component analysis (PCA). The correlation of abundances of eight taxa were examined in terms of a limited number of unobservable latent variables, principal components. The first two components could explain about 78% of total variability though it could not be shown clearly what these two principal components represented. Above mentioned three groups were well distinguished in the plot of these two component weights (Fig. 2). By component 2, the eight taxa could be divided into two, possibly migrating taxa (group 1 and 2 of above) and others (group 3 of above). (For group 3, the mesh size of 0.333 mm may not be appropriate to sample. Therefore, no evidance of vertical migration does not necessarily mean that this group do not migrate vertically.) Then migrating group could be subdivided into two by component 1. Component 1 might represent depth range of vertical migration so that vertical migration of group 1 (Bivalve larva) could be detected with the data of only upper 10 m depth while vertical migration of four taxa of group 2 might extend beyond the sampled layer. Whether or not this scenario is true, at least it can be said that some species of zooplankton do diel vertical migration even in this coastal area of shallow and active tidal mixing. Percent composition of these taxa in all was more than 50%.

DISCUSSIONS

The day-night difference in abundances can be interpreted in terms of locality unless the same water mass was sampled. To sample the same water mass, a marker buoy with drogue at proper depth may be deployed and sampling can be done around this buoy. But, this was practically impossible in this area because free drift of a marker buoy was not guaranteed due to the many sites of mariculture and small islands. As an alternative, time lag of about 12.5 hours between the day and night sampling, which was equivalent to tidal period, was made to sample the same water mass in this study. Though exactlly the same water parcels might not be sampled during the day and night, variability due to the difference in locality seemed to be eliminated successfully by the following reasons. First, surface temperature range (12.9-14.3 °C) and surface salinity range (30.0–30.7‰) were narrow enough. Second, the list of the taxa appeared was about the same for day and night. And finally, the distance between the center of water parcels sampled during the day and night did not seem to be far enough not to accept this assumption of same water mass. While sampling was done within a circle of about 3 km diameter, the water traveled maximum of about 11 km for the half period of tide since maximum tidal current speed was about 1 knot (Office of Hydrographic Affairs, 1989). Park (1989) showed that about 4 km of distance between the two stations was meaningless in the coastal area off Anhung of which environment was very similar to that of this study area. The possible maximum distance traveled by a certain water parcel was 11 km as memtioned above. However, it was based on maximum tidal speed. Since the speed of tidal current varies from 0 to maximum during the half of one tidal cycle, actual distance may be about half of 11 km, which is not so different from 4 km considering tow distance of the net. Therefore, this assumption of same water mass does not seem to be critical in interpreting the results of this study.

The other problems of this study may be the facts that the bottom layer was not sampled and the data of one layer of 5 m thickness would lose information on vertical stratification within this one layer if any. As mentioned in the result of ANOVA, the crossing point of two regression lines of abundance against depth (one for day and the other for night time, when interaction was significant) is to be found to show the vertical migration clearly. It was actually found within the sampled depth range only in case of Bivalve veliger larva. In case of *L. euchaeta* and *C. sinicus,* this crossing points were not found within the actually sampled layer though they were believed to be below 10 m depth. Though the patterns of vertical migration could not be detected because of this imperfect structure of data, the above listed results seemed to be sufficient to show at least the presense of diel vertical migration of some zooplankton in this coastal area of active tidal mixing. Stratified sampling covering whole depth range of water column with more number of layers (i.e. with thinner layer of each stratum) is needed for further study on vertical migration of zooplankton.

High abundance at night may be interpreted in terms of visual avoidance. However, as listed in Clutter and Anraku (1968), visual avoidance was significant mostly for the large size animals such as fishes, Euphausiids, and Mysids, of which visual sence organs and swimming ability were well-developed. Though avoidance effects were also reported for Copepods and Chaetognaths, tow speed of 1 m/sec seemed to enough to eliminate avoidance problem for the taxa considered in this study as indicated by Clutter and Anraku (1968).

In the past, most studies on zooplankton distribution in Korean waters were based on the data obtained by vertical tow of the net (seven cases out of eleven as shown in Table 1). Vertical tow may be a good way of sampling in getting information on biomass in that the effect of vertical migration can be excluded. But the data based on this tow type can not provide the information on species specific vertical stratification (if any as partially shown in this study) so that community structures can not be studied. In addition, vertical tow cannot successfully reduce the variability caused by patchy distribution (Park, 1989; Park *et al.,* 1989). Oblique tow may be better way in getting information on biomass only not only because this tow type can reduce the variability caused by patchiness but also it can exclude the effect of vertical migration. If community structure is to be studied, time dependent vertically stratified sampling (by horizontal or oblique tow depending on the thickness of each stratum) should be adopted as indicated by Park *et al.* (1989).

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