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VERTICAL DISTRIBUTION OF *OITHONA SIMILIS* AND *ONCAEA CURVATA* (CYCLOPOIDA, COPEPODA) UNDER SEA ICE NEAR SYOWA STATION IN THE ANTARCTIC WINTER

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Abstract: Vertical distributions of two small cyclopoid copepods, *Oithona similis* and *Oncaea curvata*, were investigated under fast ice near Syowa Station on 1–2 July in continuous darkness during the Antarctic winter. All developmental stages from copepodite stage I (CI) to adults of two species occurred homogeneously throughout the water column; and no marked diel vertical migration was observed. Their homogeneous distribution pattern and non-migrating behavior suggest some selective advantages for surviving in the Antarctic winter: reduction of the energy cost, effective utilization of the limited food resources, and minimizing the population predation.

1. Introduction

Oithona similis and *Oncaea curvata* are both small cyclopoid copepods and have been repeatedly reported as the most abundant species from open water (HOPKINS, 1985; SCHNACK *et al.*, 1985; FRANSZ, 1988; HOPKINS and TORRES, 1988; HOPKINS *et al.*, 1993) to coastal areas covered with sea ice (TANIMURA *et al.*, 1986; FOSTER, 1987; TUCKER and BURTON, 1990) in the Antarctic. Investigations on the vertical distributions of these copepods have been conducted in the open water and pack ice region mostly during the austral summer (KACZMARUK, 1983; CHOJNACKI and WEGLENSKA, 1984; HOPKINS, 1985; HOPKINS and TORRES, 1988; GONZÁLEZ *et al.*, 1994; METZ, 1995). However, their vertical distribution in winter has not yet been reported. Moreover, few previous studies have examined the vertical distribution of *Oithona similis* and *Oncaea curvata* with reference to their developmental stages.

Generally a day-night light cycle plays an important role in controlling the diel vertical migration and distribution of zooplankton in temperate and tropical regions. The polar region is a unique area in light condition, where the complete darkness prevails in winter; in contrast, continuous daylight prevails in summer. Therefore the polar region provides an interesting area for studying the environmental controls for the diel vertical distributions and migrations in zooplankton (*cf.* BUCHANAN and HANEY, 1980).

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This paper describes the diel change in vertical distributions of each copepodite stage of *Oithona similis* and *Oncaea curvata* on the basis of the samples collected from under the coastal fast ice in the Syowa Station area (69°00′S, 39°35′E) during continuous darkness in mid-winter of 1993. The ecological significance of their vertical distributions under complete darkness is also discussed. This is the first attempt to investigate the diel vertical distribution of zooplankton under continuous darkness in the Antarctic winter.

2. Materials and Methods

Zooplankton investigation was carried out at Stn. K (depth from the under surface of ice: 30 m) in Kita-no-ura Cove near Syowa Station (Fig. 1) during the mid-winter of 1993 when the sun was continuously below the horizon. Ice thickness was 140 cm and there was no snow accumulation on the ice in this period.

A series of plankton samples were collected at about 4 h intervals between 1200 on 1 July and 1200 on 2 July by using on the NIPR sampler (FUKUCHI *et al.*, 1979). A conical net with 0.1 mm mesh aperture was attached to the end of the sampler. Samples were collected from 7 selected depths from just beneath the sea ice to near the sea bottom. Sampling was performed for 5 minutes at each depth. Each sampling was finished within one hour. Samples were preserved in 5% buffered formalin-seawater.

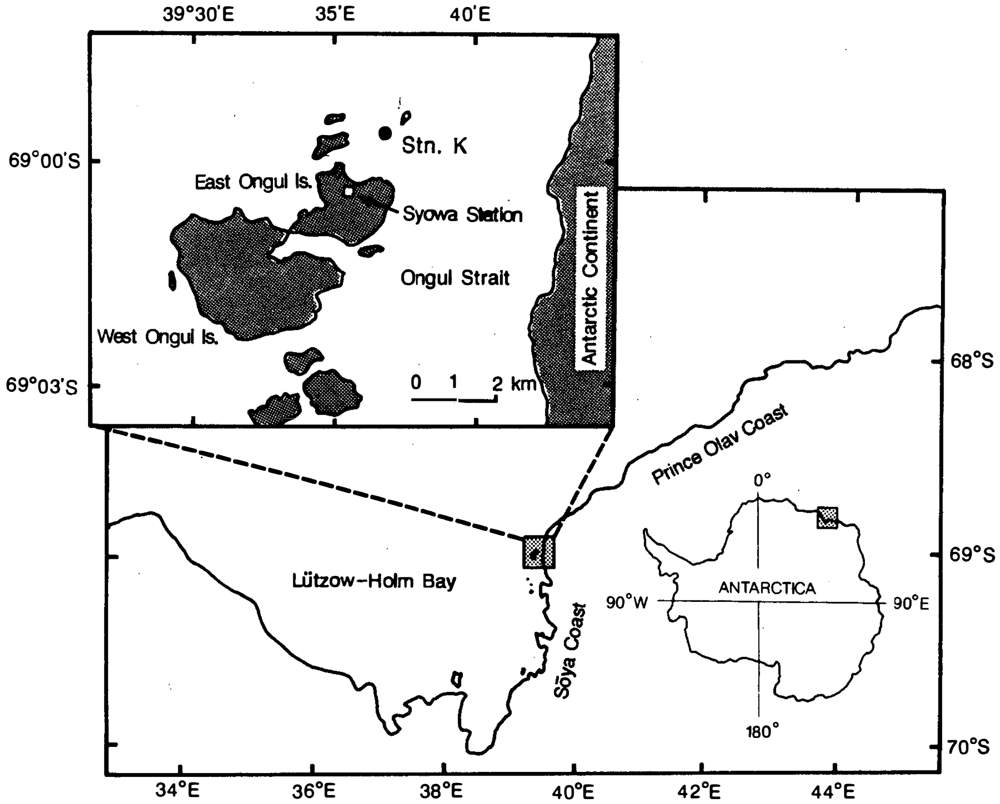

Fig. 1. Location of sampling site.

In the laboratory, all copepodite stages of *Oithona similis* and *Oncaea curvata* were counted for 1/2 aliquot. The flow rate of the sampler was estimated at roughly 200 l min^{-1}. Therefore each 5-minute sampling represents a filtration of 1 m^3 of water. However, the occurrence of each developmental stage was expressed as number of individuals per 5-minute sampling period in this study. For each developmental stage, the depth of the median population was calculated. As the data at 1200 and 1600 LT on 1 July lack reliability due to trouble in the sampler, these data were excluded from the present analysis.

At 4 h intervals, vertical profiles of temperature and salinity were recorded by using a CTD (SEACAT-19). Water for the pigment concentrations was also sampled at the every 4 hours from the same depths as for the NIPR-net sampling. Chlorophyll *a* and pheopigment concentration were measured fluorometrically (STRICKLAND and PARSONS, 1972).

3. Results

3.1. Hydrographic conditions

Hydrographic condition under sea ice varied little and was homogeneous vertically; within the water column the temperature and salinity varied only 0.05°C and 0.08 psu, respectively (Fig. 2a and b). Isotherms and isohalines moved with time, probably related to the tidal cycle (low tide at 2200 LT on 1 July; high tide at 1500 on 1 July and 0600 on 2 July).

Chlorophyll *a* concentration was less than 0.02 $\mu g l^{-1}$ throughout the water column and showed no diel variability (Fig. 2c). The relatively high chlorophyll *a* concentration (>0.02 $\mu g l^{-1}$) was observed just beneath the ice and near the bottom, suggesting the presence of ice algae and bottom sediment.

3.2. Stage composition and diel vertical distribution of Oithona similis

All copepodite stages of *Oithona similis* except for adult males occurred during all sampling periods. Figure 3 shows the abundance of each developmental stage throughout the sampling periods. *O. similis* was dominated by young copepodite stages (CII, CIII and CIV), comprising 19.4%, 28.3% and 22.9% of the total number, respectively. They were followed by old copepodite stages of the adult (15.9%) and the CV (11.7%). The copepodite stage I (CI) was found in small numbers of less than 2% of the total number.

The abundance of *O. similis* varied with time, ranging from 125 (2000 LT on 1 July) to 267 (0000 on 2 July) ind./5 min sampling period. However, the relative abundance of each developmental stage did not vary significantly during the investigation (Fig. 4).

Figure 5 shows the diel variation of vertical distribution of each stages from CI to adult. Vertical distribution pattern of CI was not clear owing to their low number and sporadic occurrence. The CII to CIV exhibited similar vertical distribution patterns during the investigation period; the population was abundant just beneath the ice and slightly decreased with depth. They did not show any remarked concentration of their populations in a certain layer at any time of the day. The mean depth and its standard

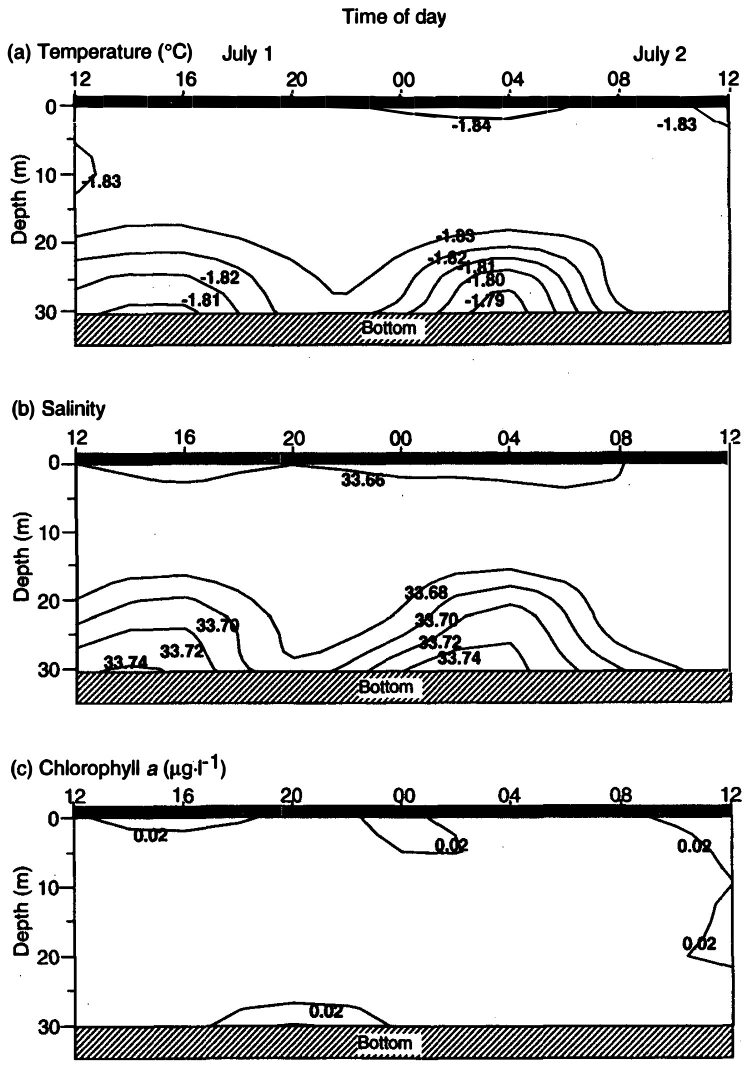

Fig. 2. Diel variation in vertical distribution of temperature (a), salinity (b) and chlorophyll a *(c) at Stn. K during the period from 1200 LT, 1 July to 1200, 2 July in 1993. Black bars represent darkness throughout the investigation period.*

deviation of median population was 9.4±1.8 m for the CII, 10.0±2.4 m for the CIII and 10.7±3.0 m for the CIV, indicating that their depth slightly increased as the developmental stage progressed. The CVs and the adults also occurred in the whole water column and exhibited a diel vertical distribution similar to the CII–CIV. The mean median depth and SD was 10.7±2.2 m for the CVs and 10.7±1.6 m for the adults, respectively, which were nearly same as in the CIV.

3.3. *Stage composition and diel vertical distribution of* Oncaea curvata

All copepodite stages of *Oncaea curvata* were found during the investigation. Figure 6 shows the abundance of each developmental stage which occurred throughout the sampling period. They were dominated by the CIII, which occupied 84.0% of the total number. The remaining fraction was comprised mainly of the CIV (10.4%), the adult (6.0%) and the CII (4.7%). The CV and the CI contributed to

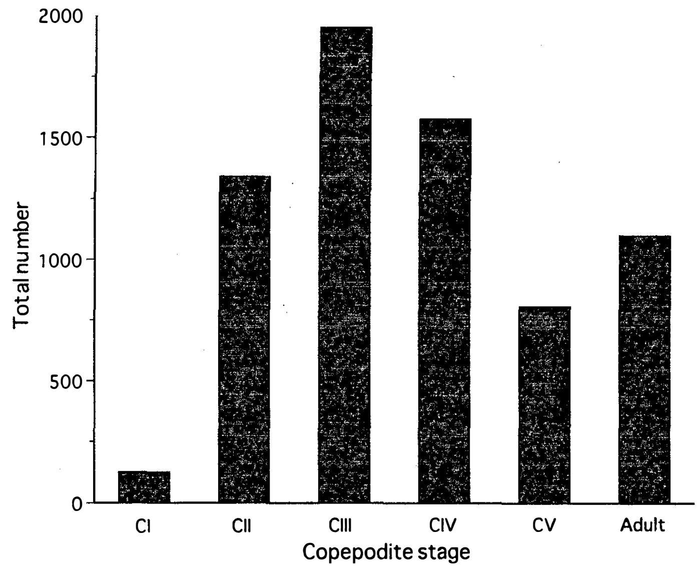

Fig. 3. Total number of each developmental stage of Oithona similis *occurring throughout the sampling period.*

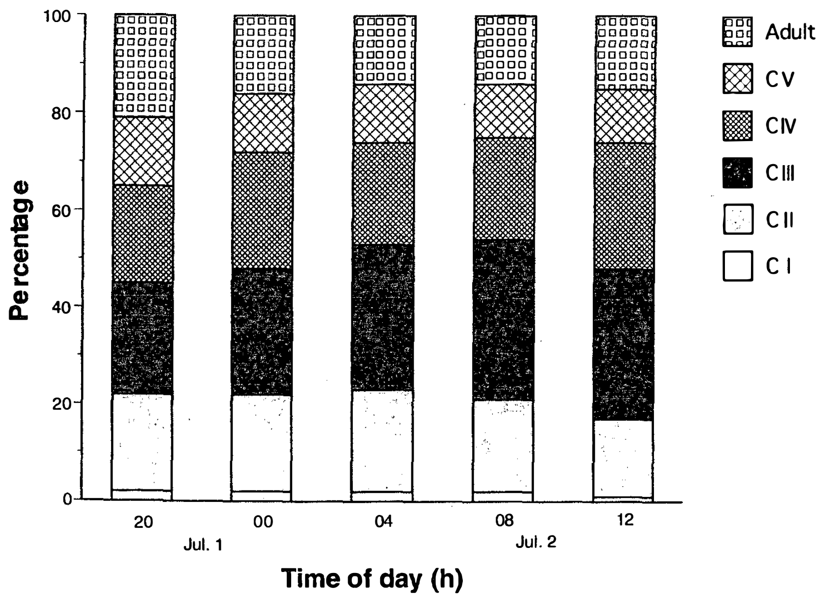

Fig. 4. Relative composition of developmental stages of Oithona similis *at each sampling time.*

only 0.5% and 0.1%, respectively. *O. curvata* is narrower than *O. similis.* Probably the considerable number of early copepodite stages of *O. curvata*, especially CI and CII whose width was less than 100 μm, may have passed through a 100 μm net.

Although the abundance of *O. curvata* varied with the time of day, the stage composition was constant as in *O. similis* (Fig. 7).

Figure 8 shows the diel variation of vertical distribution of copepodite stages from the CIs to the adults. The CIs occurred in small numbers only in the upper layer at 0800 LT. The CIIs were distributed throughout the water column, while the

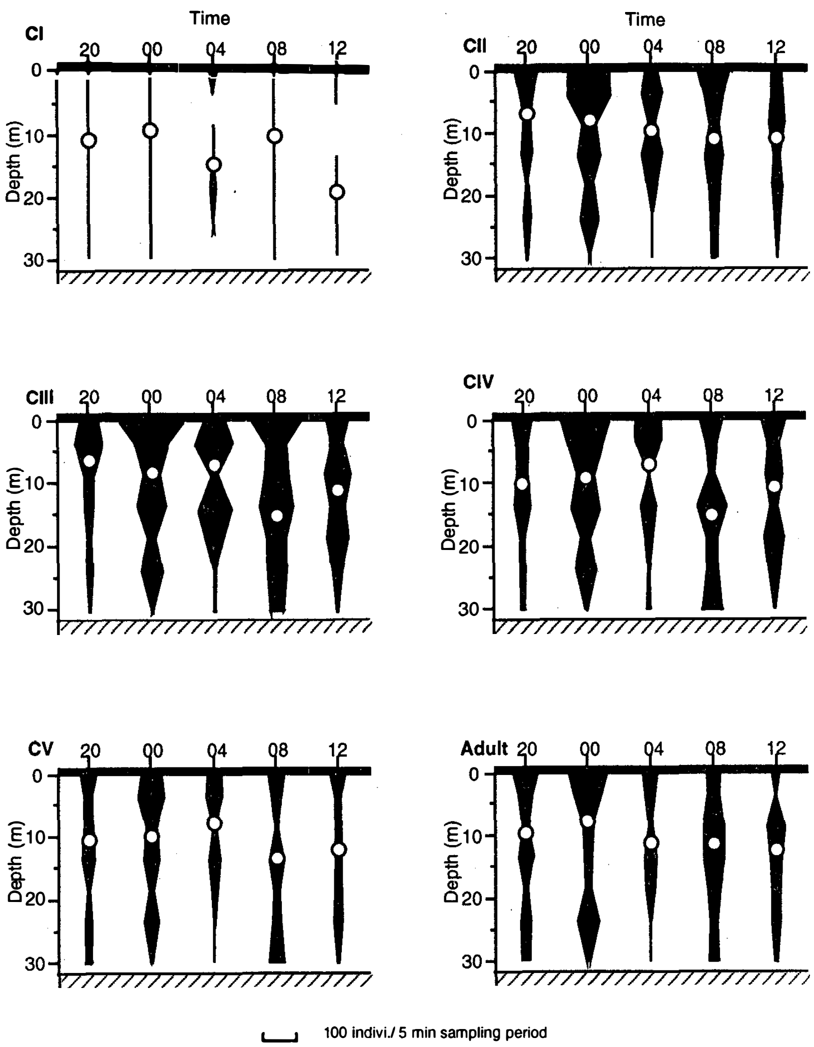

Fig. 5. Diel variation in vertical distribution of copepodites (CI to CV) and adults of Oithona similis *collected at Stn. K under sea ice from 2000 LT, 1 July to 1200, 2 July 1993. Open circles indicate median population depth. Black bars represent darkness throughout the investigation period.*

majority were found in the upper 15 m layer. The mean median depth was 7.7±2.3 m. The CIIIs were also distributed throughout the water column. They were abundant just beneath the ice and decreased with depth. However, the majority of the population stayed in the upper 20 m at all times, showing a broader vertical distribution than that of the CIIs. The depth of the median population ranged between 7.2 m (1200 LT) and 12.2 m (0800) (daily mean: 9.7±2.1 m), without marked vertical movement. The CIV males and females showed a similar vertical pattern. They tended to be broadly distributed throughout the water column as were the CIIIs. The depth of the median CIV population ranged from 11.5 m (2000 LT) to 13.4 m (0800) with daily mean of 12.5±0.8 m showing no clear diel vertical migration. The CVs seemed to be distributed mainly in the upper 15 m layer throughout the study, although their diel vertical pattern was not clear owing to small numbers. The

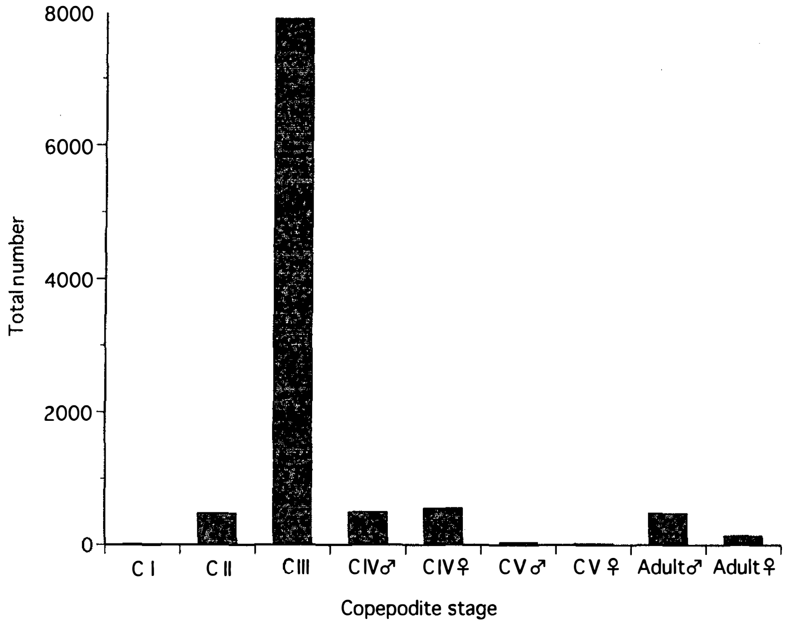

Fig. 6. Total number of each developmental stage of Oncaea curvata *occurring throughout the sampling period.*

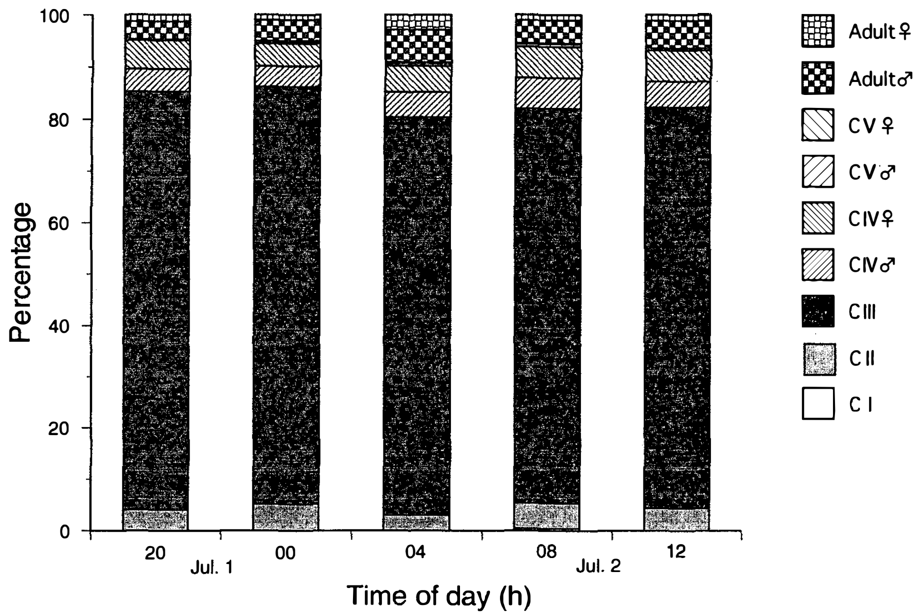

Fig. 7. Relative composition of developmental stages of Oncaea curvata *at each sampling time.*

vertical distribution of adult males and females was similar to that of the CIV. However, the median depth range extended to deeper layers (daily mean: 13.5±3.5 m).

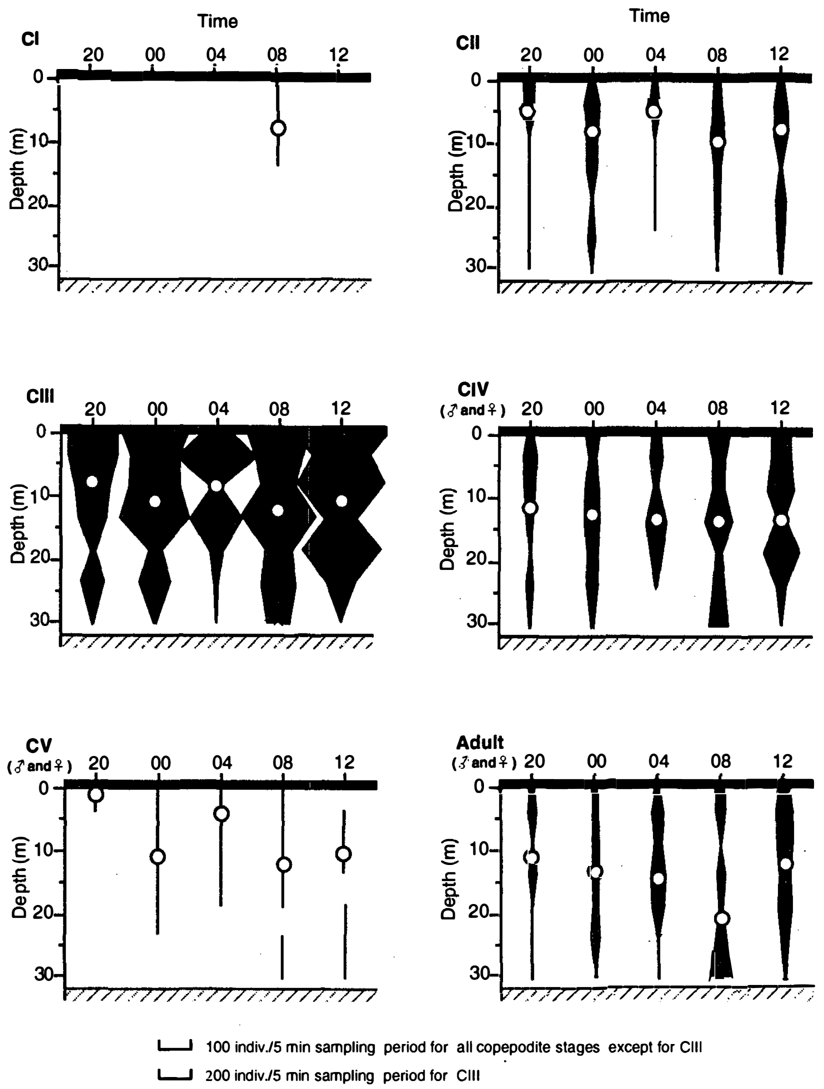

Fig. 8. Diel variation in vertical distribution of copepodites (CI to CV) and adults of Oncaea curvata *collected at Stn. K under sea ice from 2000 LT, 1 July to 1200, 2 July 1993. Open circles indicate depth of median population. Black bars represent darkness throughout the investigation period.*

4. Discussion

There has been no study of the vertical distribution of *Oithona similis* and *Oncaea curvata* in the ice covered shallow coastal water in Antarctica. Moreover, observation of the distribution of these species during the complete darkness period in winter has never been done before. Vertical distribution of *O. similis* and *O. curvata* have been observed in the ocean under almost continuous daylight in summer in the Weddell Sea (Metz, 1995) and under clear diel light-dark cycles in autumn in Bransfield Strait (Hopkins, 1985). In these two areas under different light conditions, *O. similis* occurred mainly in the surface 100 m of several hundred meters depth while *O. curvata* was inhabiting a slightly deeper and more dispersed layer than *O. similis*

(METZ, 1995; HOPKINS, 1985). In the subantarctic area around South Georgia Islands, ATKINSON and PECK (1988) observed the summer–winter difference in vertical distributions of *Oithona* and *Oncaea*; then they demonstrated similar distributional patterns to those observed in the Weddell Sea and the Bransfield Strait.

In the present study in the ice covered shallow coastal water, *O. similis* and *O. curvata* were homogeneously distributed throughout the water column during continuous darkness in mid-winter. Complete darkness throughout the day extinguishes the vertical gradient of light and produces an optically homogeneous environment throughout the water column. Ambient temperature and salinity also indicated that the water column was hydrographically quite homogeneous under the ice during this investigation (Fig. 2). Chlorophyll *a* concentration was also extremely low (less than 0.1 μgl^{-1} throughout the water column) during the present study (Fig. 2). During periods of complete darkness in mid-winter, the underwater environment at Syowa Station was optically, hydrographically and biologically homogeneous. Lack of these environmental gradients in the whole water column under the sea ice would allow copepods distributing homogeneously in the water column.

It is generally accepted that day and night light cycles play an important role in regulating the diel vertical migrations of zooplankton populations (*e.g.* DAVIS, 1984). The rapid changes in the light intensity, particularly around sunset and sunrise, initiate the migrations (ENRIGHT and HONEGGER, 1977). BOGOROV (1946) found that the diel vertical migrations of zooplankton were absent or less marked under continuous daylight in mid-summer in the Barents Sea. He suggested that disappearance of diel light-dark cycles in polar regions suppressed the diel migration in zooplankton. Similar findings were also reported by DIGBY (1954) for some coastal zooplankton off Spitsbergen during midsummer. BUCHANAN and HANEY (1980) showed that diel migrations are lacking for the Arctic zooplankton under continuous daylight in laboratory experiments.

In the present study, *O. similis* and *O. curvata* did not perform diel vertical migration under continuos darkness in mid-winter. Probably complete darkness, which is the opposite of continuous daylight in mid-summer, also suppressed the diel vertical migration of some zooplankters as found under continuous daylight.

Our results, homogenous distribution and non diel vertical migration, imply selective advantages for *O. similis* and *O. curvata* to survive in winter under the sea ice. Non-migration would result in reduction of the energy cost in winter. Generally *Oithona* and *Oncaea* have low metabolic expenditure (PAFFENHÖFER, 1993). It would be advantageous to keep lower metabolism to survive under extremely low food condition. To utilize such limited food resources more effectively, a homogenous distribution could be much better for their survival. The homogeneous distribution would also minimize the population predation. One of the important predators of *O. similis* and *O. curvata* under sea ice around Syowa Station is a nototheniid fish, *Pagothenia borchgrevinki*. Their fry feed exclusively on the large sized copepods just beneath ice (HOSHIAI and TANIMURA, 1981). Therefore, predation avoidance by homogeneous or dispersal distribution would be an important strategy for large sized older stages (CV or adults) of *O. similis* and *O. curvata*.

Both *O. similis* and *O. curvata* are suspension-feeders and feed exclusively on diatoms and detrital materials in summer when phytoplankton standing crop is high in the Antarctic permanent ice zone (HOPKINS, 1987). However, generally *Oncaea* have more opportunistic feeding behavior than *Oithona* (OHTSUKA and KUBO, 1991; GONZÁLEZ *et al.*, 1994). METZ (1995) suggested a possible change of feeding behavior in *O. similis* and *O. curvata* from herbivor to omnivor and/or carnivor during winter with extremely low phytoplankton biomass. It is speculated that *O. similis* and *O. curvata* would utilize different types of food under sea ice during winter. This would be consistent with the fact that they show similar distributional patterns. More detailed investigations of distribution and feeding ecology under the sea ice are necessary to fully understand the survival strategy of these copepods.

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