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COMPARISON OF ZOOPLANKTON ABUNDANCE UNDER SEA ICE BETWEEN NIPR NET AND NORPAC NET SAMPLINGS, IN LAGOON SAROMA KO, HOKKAIDO

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Abstract: Zooplankton under sea ice were collected vertically and horizontally at two stations (7–11 m depth) in lagoon Saroma Ko, Hokkaido, on February 21–24, 1986, and their abundance was compared by haul, mesh size, depth, sampling duration, and sampling station. Vertical hauls from the bottom to the surface were made with a standard Norpac net and its modified net, and horizontal samplings with a NIPR net (under-ice plankton sampler) from 0.3, 2 and 5 m, and bottom layers. Three mesh sizes, 100, 330 and 505 μ, were used for each net. Copepods (mostly *Pseudocalanus* sp.) and chaetognath (*Sagitta elegans*) predominated the biomass in weight and number with a few amphipods. In vertical hauls with 100 μ-mesh Norpac net, the copepod abundance was similar between the two stations, while the chaetognath abundance was significantly greater at Stn. 11 than at Stn. 3. In horizontal samplings with the 100 μ-mesh NIPR net, copepods were very abundant in the 0.3 and 2 m layers, but were fewer in the 5 m and bottom layers. Chaetognath revealed a distinct vertical stratification with a highest abundance in the 2 m layer and scarcity in the 0.3 m and bottom layers. Compared with a 5-min filtration, the 10- and 15-min filtration in the 330 μ- and 505 μ-mesh NIPR nets showed a decrease of the zooplankton catches per unit time. The modified Norpac net collected significantly abundant chaetognath than the standard Norpac net, but not for copepods.

1. Introduction

The development of the sampling gears of zooplankton under sea ice has been a central problem to marine ecologist in the subarctic and polar regions. Since the National Institute of Polar Research of Japan has devised an under-ice plankton sampler, NIPR-I net, (FUKUCHI *et al.*, 1979), its capability has been demonstrated in the antarctic (FUKUCHI and SASAKI, 1981; TANIMURA *et al.*, 1984) and arctic (FUKUCHI *et al.*, 1981). The handiness of this gear and easy operation allow the use in a remote ice field. Yet, the NIPR net appears to require modification and improvement to obtain its legitimate position of an under-ice plankton sampler in the ecological in-

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vestigations.

The important aspect with regard to the sampling of the under-ice plankton is twofold: reliability and readiness. First, in addition to the proper design and function against the extreme physical conditions of the ice field, the gear must collect an adequate amount of sample which renders the analyses of population characteristics, community structure, or spatial distribution patterns of planktonic organisms in the ice-covered water column. Second, the time efficiency is essential, since much time is required to drill ice holes, depending on the thickness and shape of ice and the dimension of ice opening needed for research. For example, it takes 3–4 h to drill a 50×60 cm hole in the 1–2 m thick fast ice of Antarctica (FUKUCHI, 1982). While the operation is under way, scientific party is exposed to severe sub-zero temperature, fickle weather or often blizzard. Such conditions cause hypothermia and poor sight, and hence result in the inefficiency of operation or loss of maneuverability of sampling gears. Besides, the short daytime period in winter in the subarctic region unfavorably restricts the working time, and makes transportation uneasy and dangerous. To overcome these limitations, the sampling strategies must be improved in any possible ways, particularly to minimize the sampling time at a station.

This report describes the results of the zooplankton samplings under sea ice in lagoon Saroma Ko: (1) to find appropriate sampling procedures for the under-ice zooplankton in terms of mesh size of net, depth of layer, and the duration of sampling period; (2) to compare the plankton abundance between vertical haul by the Norpac net and horizontal tow by the NIPR net; and (3) to depict a vertical profile of abundance distribution in water column under ice.

2. Materials and Methods

2.1. *Sampling station*

Lagoon Saroma Ko is located on the Okhotsk Sea side of Hokkaido, Japan. The lagoon is elongate with an area of 150 km^2, connected with the Okhotsk Sea by two inlets (KIKUCHI *et al.*, 1984), and covered with winter fast ice during December through April. The greatest depth is 19.5 m. We selected two stations, Stns. 3 and 11, to perform the zooplankton samplings among 14 stations which were taken to collect the ice, ice microflora and water samples during a period from February 22 and 24, 1986 (Table 1). The distance between these two stations was about 1 km, and the

Table 1. Data on samplings of under-ice plankton in lagoon Saroma Ko, Hokkaido, Japan in February 1986.

Stn. No.	Sampling			Depth of water (m)	Thickness of ice (cm)	Water temperature (°C)
	date	time	net			
3	Feb. 22	1340–1539	NIPR	11.4	29.0	−1.5
		1407–1518	STD Norpac			
		1425–1442	MDF Norpac			
	Feb. 23	1027–1308	NIPR			
11	Feb. 24	0937–1122	NIPR	7.5	24.7	−1.5
		0939–1028	STD Norpac			

depth of water was 11.4 m at Stn. 3 and 7.5 m at Stn. 11. The ice thickness was 25–29 cm and water temperature at 0.3 m beneath the ice was −1.5°C.

2.2. Sampling net, mesh size and sampling procedure

We used three plankton sampling gears: standard Norpac net, modified Norpac net, and NIPR net. Three mesh sizes, 100, 330 and 505 μ were used for each net. To avoid the effects of clogging and age of net, a brand-new net was used in every sampling.

1) Standard Norpac net: A standard Norpac net (abbreviated STD Norpac net hereafter) is conical, 45 cm in diameter and 180 cm in length (MOTODA, 1957). The frame of ring is made of solid steel. The net was vertically hauled from the bottom to the surface at a speed of 1 m per second. A flow meter (Rigosha Co.) was installed in the center of the ring so that the volume of water filtered could be calculated at each cast.

2) Modified Norpac net (MDF Norpac net): This net has the same dimensions as does STD Norpac net except the mouth ring (A. TANIMURA, unpublished). The ring of the MDF Norpac net is replaced by a thick rubber tube, 3 cm in diameter. The flexibility of the rubber frame permits to cast the net from a smaller ice hole than the dimension of the mouth ring of the STD Norpac net. The net mouth opens normally in water while heaving, and can be closed when retrieved from an ice hole. Ideally this contributes to save the time in making an ice hole. However, attachment of a flow meter is sacrificed. Sampling depth and speed of tow were the same as in the STD Norpac net sampling.

3) NIPR net: The general specifications of the NIPR net have been described by FUKUCHI *et al.* (1979). This net is horizontally suspended in water from an ice hole by a line and can be placed at any desired depth between the bottom and the surface beneath the ice. The net is composed of a cylindrical case, 20 cm in diamter and 57.5 cm in length, and a conical plankton net (39 cm in length) is attached to one end of the case. Plankton are expelled from the other end of case into the net by a current generated by a rotating propeller and an electric motor installed inside the cylinder, and are filtered by the net. The portable electric generator (AC 100V) was used as a power source to drive the motor. A resistance gauge attached to the generator permits to monitor the relative flow condition of water in the net and to manipulate the rotation of propeller by adjusting the voltage. The net in water was visually observed from the ice hole during sampling, and the normal opening was ascertained at each sampling. Although the direction of the NIPR net was not fixed in water, the net did not swing freely with a deviation more than 30° in a horizontal plane.

We made two rectangular and square holes at each station. The dimension of these holes was a 1×0.5 m opening for the NIPR net sampling and a 0.5×0.5 m opening for the Norpac net sampling. These two holes were 10 m apart from each other. All the samplings were undertaken during daytime and the ice hole remained uncovered until next sampling time. No particular care was taken to eliminate the effect of light penetration in water through ice hole.

2.3. Sample processing and statistical method

The plankton samples obtained were fixed in 10% buffered sea water formalin.

In laboratory, the whole wet weight of sample was measured nearest to 0.001 g by a digital balance. The zooplankton were then sorted into taxonomical groups. The dominant zooplankton in this study were *Pseudocalanus* sp. and *Sagitta elegans*, with a few amphipods. *Calanus plumchrus*, *Acartia* spp. and *Oithona* spp. were also found, but their weights were very low. Each zooplankton group was separately weighed, and chaetognath and amphipod were enumerated. The weight of sample taken from the bottom layer with the NIPR net at Stn. 11 is probably biased due to the remnant and debris of seagrass (*Phyllospadix iwatensis* sp.) and fine sand, though these were removed as possible as could.

Mean and variance of the weight or number of zooplankton groups were compared between different hauls, depths, mesh sizes, sampling durations and sampling stations in one-way or two-way analysis of variance (*F*-test) (ZAHR, 1974). The weight or number of zooplankton (X) per haul or per unit volume of water was transformed in logarithm (X+1), as variance exceeded the mean in several cases. In comparison of the water volume filtered among different mesh sizes, the actual value of volume was used because of low variability. When there was significant difference in *F*-value, the difference among means was compared by the Newman-Keuls multiple range tests.

3. Results

3.1. Norpac net samplings

3.1.1. Comparison of volume of water filtered by net mesh

In this study, only vertical hauls with the STD Norpac net provided quantitative data for the calibration of the water volume filtered through the net mesh and for the abundance of zooplankton per unit volume ot water.

At Stn. 3, the volume filtered through the net varied between 1.21 and 1.62 m^3 among 9 hauls (Table 2). The mean volume was 1.31 m^3 in 100 μ mesh, 1.35 m^3 in 330 μ mesh and 1.51 m^3 in 505 μ mesh, showing an increasing trend in larger meshes.

Table 2. Range and mean±standard deviation (SD) of water volume filtered and abundance in weight and number of zooplankton groups in three hauls collected vertically from 10 m depth with the STD Norpac net at Stn. 3, lagoon Saroma Ko, February 22, 1986.

	Mesh size (μ)		
	100	330	505
Water volume filtered (m^3)			
Range	1.29−1.34	1.21−1.49	1.41−1.62
Mean±SD	1.31±0.03	1.35±0.14	1.51±0.11
Copepod in weight ($g \cdot m^3$)			
Range	0.33−0.39	0.09−0.11	0.03−0.05
Mean±SD	0.36±0.03	0.10±0.01	0.04±0.01
Chaetognath in weight ($g \cdot m^3$)			
Range	0.24−0.36	0.17−0.50	0.19−0.54
Mean±SD	0.30±0.01	0.31±0.17	0.30±0.19
Chaetognath in number			
Range	11.2 −14.7	8.7 −22.3	8.0 −24.1
Mean±SD	13.0 ± 1.8	14.8 ± 6.9	14.9 ± 8.3

The F-value in two-way analysis of variance (9.962) rejects a null hypothesis that the volume was the same among the three meshes ($F_{0.05,(2,4)}=6.94$, $P=0.031$). In this case, each haul in a triplicate sampling by the same mesh was regarded as an independent sample. The Newman-Keuls multiple range test shows that the mean volume in 505 μ mesh was significantly greater than those in 100 μ ($Q=5.855>Q_{0.05,4,3}=5.040$) and 330 μ meshes ($Q=4.684>Q_{0.05,4,2}=3.927$) at $\alpha=0.05$, while the difference between the latter two meshes was insignificant ($Q=1.171<Q_{0.05,4,2}=3.927$). The significant difference between hauls ($F=7.033$, $P=0.050$) derived from the variability in 330 μ and 505 μ meshes.

At Stn. 11, the water volume was low in 100 μ mesh (0.79 m^3), but slightly high in 330 μ (0.88 m^3) and 505 μ meshes (0.89 m^3) (Table 3). There was a significant difference among the three meshes ($F=7.000$, $P=0.051$). The mean volume of 100 μ mesh was lower than that of 330 μ mesh ($Q=4.324>Q_{0.05,4,2}=3.927$), while there was no difference between 330 μ and 505 μ meshes ($Q=0.480<Q_{0.05,4,2}=3.927$). A difference of volume between hauls was insignificant ($F=4.692$, $P=0.09$).

3.1.2. Difference of zooplankton abundance by mesh and haul

At Stn. 3, the abundance in weight of copepods varied considerably with mesh size (Table 2). The abundance in g per m^3 in 100 μ mesh was 0.36 g, 3.6 times greater than in 330 μ mesh, and 9 times greater than in 505 μ mesh. The abundance in 330 μ mesh was 2.5 times higher than in 505 μ mesh. The analysis of variance shows that the abundance differed significantly by mesh size ($F=194.486$, $P=0.003$), but not by haul ($F=0.244$, $P=0.795$). In the multiple range tests, the mean abundance was shown to be different among the three meshes at $\alpha=0.05$.

Contrarily, the chaetognath abundance was almost the same regardless of mesh size: the average weight was 0.30 g in 100 μ mesh, 0.31 g in 330 μ mesh, and 0.33 g in 505 μ mesh. Correspondingly, the average number was similar among the three mesh sizes (13.0 in 100 μ mesh, 14.8 in 330 μ mesh, and 14.9 in 505 μ mesh), though the variability between hauls increased in larger meshes. There was no significant

Table 3. Range and mean±standard deviation (SD) of water volume filtered and abundance in weight and number of zooplankton groups in three hauls collected vertically from 7 m depth with the STD Norpac net at Stn. 11, lagoon Saroma Ko, February 24, 1986.

	Mesh size (μ)		
	100	330	505
Water volume filtered (m^3)			
Range	0.74−0.85	0.84−0.97	0.86−0.91
Mean±SD	0.79±0.05	0.88±0.08	0.89±0.03
Copepod in weight ($g\cdot m^3$)			
Range	0.27−0.39	0.11−0.21	0.05−0.11
Mean±SD	0.33±0.031	0.17±0.05	0.08±0.03
Chaetognath in weight ($g\cdot m^3$)			
Range	0.59−0.70	0.53−0.80	0.31−0.77
Mean±SD	0.64±0.06	0.67±0.14	0.40±0.25
Chaetognath in number			
Range	22.9−33.8	25.8−39.3	14.3−30.8
Mean±SD	28.9± 5.5	32.8± 6.8	25.1± 9.4

difference among meshes in weight (F=0.05, P=0.952) and in number (F=0.066, P=0.937), while the values between hauls were highly significant in weight (F=11.109, P=0.025) and in number (F=8.970, P=0.035) resulting from a high variability in 330 μ and 505 μ meshes.

At Stn. 11, the mean copepod abundance in 100 μ mesh (0.33 g m^3) was approximately 2 times greater than in 330 μ mesh and 4 times greater than in 505 μ mesh (Table 3). The abundance in 505 μ mesh was half of 330 μ mesh. The abundance was highly variable among meshes (F=69.38, P=0.002) and between hauls (F=7.802, P=0.043). The multiple range tests indicate that the mean copepod weight was significantly different from each other at α=0.05, derived from the fluctuation of weight by haul in 505 μ mesh. Like at Stn. 3, chaetognath varied slightly among three meshes in weight (0.64 g m^3 in 100 μ, 0.67 in 330 μ, 0.40 in 505 μ), and in number (28.9 in 100 μ, 32.8 in 330 μ, 25.1 in 505 μ). The F-value shows that the chaetognath abundance did not differ significantly by mesh size (F=0.374, P=0.712), and by haul (F=4.165, P=0.106). Similarly, no difference was found in number among meshes (F=2.292, P=0.217) and between hauls (F=6.691, P=0.054).

Thus, the decreased abundance of copepods in 330 μ and 505 μ appears only incidental net retention as a result of mesh selectivity. Accordingly, quantitative comparison of the copepod abundance in larger meshes is unreliable. In contrast, the mean catch of chaetognath was almost consistent regardless of mesh size. The seizure of chaetognath by smaller mesh is invariable, and therefore the smaller meshes are preferable for quantitative comparison.

3.1.3. Difference of zooplankton abundance between STD and MDF Norpac nets

The difference in abundance of copepods and chaetognath between the STD Norpac net and the MDF Norpac net was examined on the 100 μ mesh sample, as this mesh size yielded the smallest variability within hauls. The catch data with the STD Norpac net used here is the same as given in Table 2, but instead of the abundance per unit volume of water, the abundance per haul was employed to compare with the values of the MDF Norpac net which lacked the water volume data. Assuming the water volume was the same among hauls, one-way analysis of variance was made

Table 4. Range and mean±standard deviation (SD) of abundance in weight and number of zooplankton groups in three hauls collected vertically from 10 m depth with the STD and the MDF Norpac net at Stn. 3, lagoon Saroma Ko, February 22, 1986. The mesh size was 100 μ in both nets.

	Kind of net	
	STD net	MDF net
Copepod in weight (g·m^3)		
Range	0.35–0.52	0.39–0.43
Mean±SD	0.43±0.09	0.41±0.02
Chaetognath in weight (g·m^3)		
Range	0.32–0.46	0.65–1.06
Mean±SD	0.39±0.07	0.80±0.23
Chaetognath in number		
Range	15–19	28–49
Mean±SD	17.0± 2.0	35.0±12.1

between the two nets.

In copepods, the mean abundance per haul was 0.43 g in the STD Norpac net and 0.41 g in the MDF Norpac net, with little difference between the nets (Table 4). A low *F*-value of 0.189 ($F_{0.05,(1,4)}=7.71$, $P=0.686$) leads to accept a null hypothesis that the abundance was the same between the STD Norpac net and MDF Norpac net samples. In contrast, the chaetognath abundance differed greatly by net: the mean abundance was 0.39 g in the STD Norpac net and 0.80 g in the MDF Norpac net, a 50% difference. The higher abundance in the MDF Norpac net is also reflected on the numerical abundance (35.0), twice the value of the STD Norpac net. The *F*-value of 10.552 ($P=0.320$) indicates a significant difference between the two nets. Likewise, the difference in number was significant ($F=11.828$, $P=0.027$).

Consequently, the sampling efficiency was the same between the STD Norpac net and the MDF Norpac net for copepods, but not for chaetognath. The MDF Norpac net caught more numerous chaetognath than did the STD Norpac net.

3.2. *NIPR net sampling*

3.2.1. Effect of sampling duration on zooplankton abundance

The effect of the sampling duration on the zooplankton abundance in the NIPR net sampling was examined in a 0.3 m depth layer of Stn. 3, by changing the time for 5, 10 and 15 min. For comparison, the zooplankton abundance was standardized as wet weight in g per 5-min filtration. In addition, the individual number per 5-min filtration was compared for chaetognath and amphipod.

Table 5. Abundance in weight and number of zooplankton groups collected at 0.3 m under ice with the NIPR net with different mesh size for different sampling duration at Stn. 3, lagoon Saroma Ko, February 22, 1986.

Duration (min)	Wet weight (g)			Number	
	Copepod	Chaetognath	Amphipod	Chaetognath	Amphipod
			Mesh 100 μ		
5	0.92	0	0.05	0	2
10	2.21	0.03	0.13	3	8
15	2.58	0.09	0.24	6	10
			Mesh 330 μ		
5	0.42	0	0.06	0	4
10	0.66	<0.01	0.11	1	4
15	0.64	0.04	0.12	5	7
			Mesh 505 μ		
5	0.20	0.13	0.02	7	1
10	0.21	0.07	0.04	3	2
15	0.15	0.11	0	6	0

In 100 μ mesh each zooplankton group steadily increased as the filtration time prolonged, whereas this trend was obscure in larger meshes (Table 5). The mean weight of copepods per 5-min filtration was 0.96 ($\pm$0.13) g, 0.32 ($\pm$0.11) g, and 0.12 ($\pm$0.08) g for 100, 330 and 505 μ meshes, respectively. The *F*-value of 4.082 in two-way analysis of variance indicates that the abundance did not differ significantly among the three sampling durations ($F_{0.05,(2,4)}=6.94$, $P=0.109$). The low abundance in larger meshes was distinct among three mesh sizes (F=99.563, P=0.001), as was found in the Norpac net samplings. Relative to 100 μ mesh, the abundance was 33% in 330 μ mesh and 13% in 505 μ mesh. It is notable that these ratios almost coincide with those found in the vertical hauls.

The abundance of chaetognath in weight was relatively low, and did not differ significantly by sampling duration (F=0.234, P=0.802) and by mesh size (F=2.740, P=0.178). Likely, the number of chaetognath was almost uniform, except a 5-min filtration with 505 μ mesh, irrespective of sampling duration (F=0.278, P=0.772) and mesh size (F=1.532, P=0.320). In 330 μ and 505 μ meshes, the catch decreased inversely with the prolonged filtration duration.

The amphipod abundance did not change with the sampling duration (F=0.390, P=0.703), but differed significantly by mesh size (F=11.186, P=0.025). In numerical comparison, there was no difference by the sampling duration (F=0.517, P=0.634), but a significant difference was found between meshes (F=23.302, P=0.008).

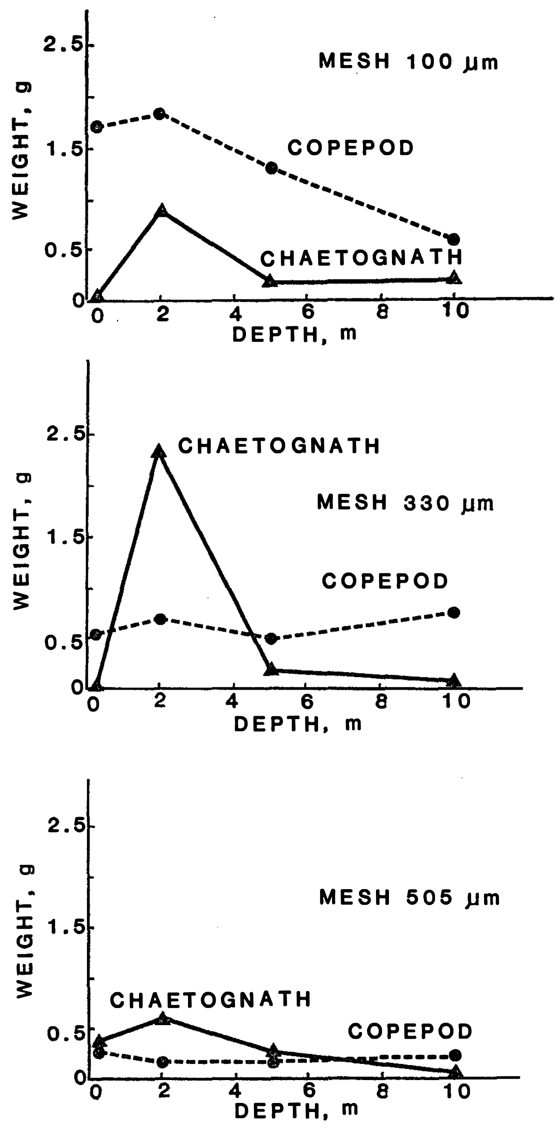

Fig. 1. Vertical distribution of zooplankton abundance collected with the NIPR net for 10-min filtration at Stn. 3, lagoon Saroma Ko, Hokkaido, Japan, February 22, 1986.

Table 6. Abundance in weight and number of zooplankton groups collected with the NIPR net for 10 min at different depths under ice at Stn. 3, lagoon Saroma Ko, February 22, 1986.

Depth (m)	Wet weight (g)			Number	
	Copepod	Chaetognath	Amphipod	Chaetognath	Amphipod
			Mesh 100 μ		
0.3	1.72	0.02	0.09	1	5
2	1.83	0.88	0.15	55	7
5	1.28	0.16	0	7	0
10	0.59	0.20	0	11	0
			Mesh 330 μ		
0.3	0.52	0	0.01	0	1
2	0.67	2.33	0	117	0
5	0.48	0.16	0	10	0
10	0.75	0.06	0	3	0
			Mesh 505 μ		
0.3	0.25	0.37	0	18	0
2	0.16	0.61	0.02	35	1
5	0.16	0.25	0.01	12	1
10	0.22	0.04	<0.01	2	1

The results clearly demonstrate that the catch of zooplankton with 100 μ mesh was proportional to the filtration duration, while it remained constant or even decreased in 330 μ and 505 μ meshes. Like in vertical hauls with the Norpac net, inconsistency in catch with the larger mesh sizes was apparent.

3.2.2. Difference of zooplankton abundance by depth

At Stn. 3, copepods in 100 μ mesh occurred very abundantly in the 0.3 and 2 m layers, while they decreased fairly at the lower depths (Fig. 1 and Table 6). The abundance in the 2 m layer exceeded 3 times than the value in the bottom layer. Unlikely, the abundance in 330 μ and 505 μ meshes was vertically similar in a range of 0.48–0.75 g and 0.16–0.25 g, respectively. The uniformity in vertical profile in these meshes can be attributable to the mesh selectivity, as seen in the previous sections. The F-value of 0.580 does not show the significant difference among the four depths ($F_{0.05,(3,6)}=4.76$, $P=0.652$), while it showed the difference between meshes ($F=14.363$, $P=0.006$).

In contrast to copepod, chaetognath revealed a pronounced abundance variation in all the three meshes (Table 6). The abundance peaked in the 2 m layer, while it was least in the 0.3 m and bottom layers. This characteristic profile was also ascertained in the numerical distribution with depth. Most notably, in 330 μ mesh the number of chaetognath was greatest at 2 m depth with a sharp decline in 0.3, 5 and 7 m layers. The F-test indicates a highly significant difference between depths ($F=5.477$, $P=0.038$), but not between mesh sizes ($F=0.229$, $P=0.803$). The mean weight in 2 m layer was significantly higher than in 0.3 m ($Q=4.767>Q_{0.05,6,2}=3.461$), 5 m ($Q=4.317>Q_{0.05,6,2}=3.461$) and 10 m layers ($Q=4.883>Q_{0.05,6,3}=4.339$), while the mean value did not differ from each other in the remaining depth layers. In number, however, there was not significant difference both by depth ($F=4.684<F_{0.05,(2,6)}=4.76$, $P=0.052$) and by mesh ($F=0.160$, $P=0.856$). The discrepancy in the results of significance test between weight and number suggests the difference in size composition

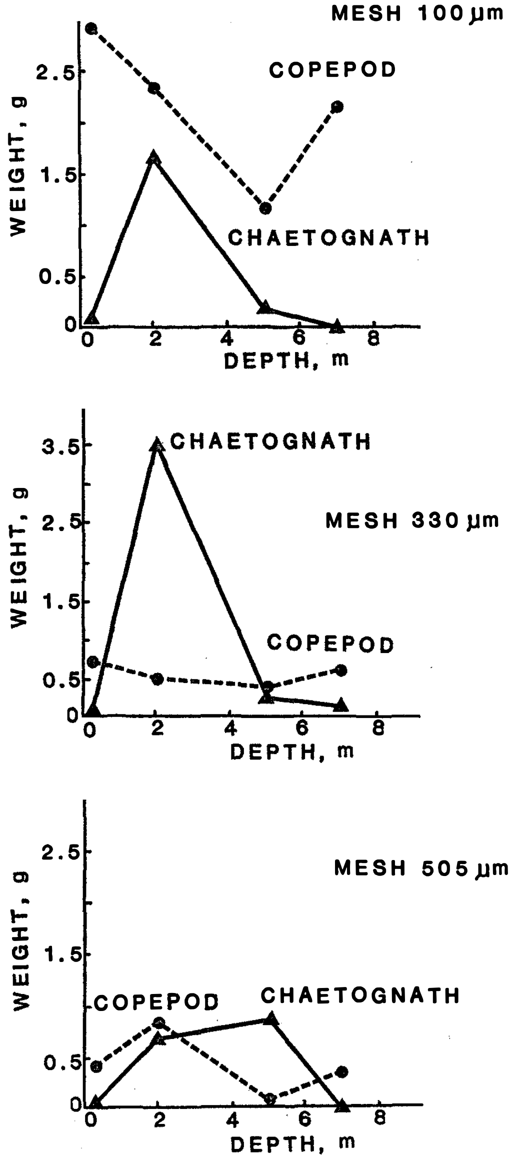

Fig. 2. Vertical distribution of zooplankton abundance collected with the NIPR net for 10-min filtration at Stn. 11, lagoon Saroma Ko, Hokkaido, Japan, February 24, 1986.

of chaetognath with depth.

At Stn. 11, copepods in 100 μ mesh were vertically abundant at 0.3 and 2 m depths, and decreased at 5 m depth, and again increased at the bottom (Fig. 2 and Table 7). The high value at the bottom is suspicious. It must be reminded that the sample from the bottom layer contained remnant and debris of seagrass and sand, so that this value probably reflected the inclusion of these materials. Even if this was the case, however, a high abundance is likely, as the similar profile was recognized in the 330 μ and 505 μ mesh samples. The F-value of 4.625 shows the insignificant difference in abundance by depth ($F_{0.05,(3,6)}=4.76$, $P=0.053$). The different abundance by mesh size is closely related to the mesh selectivity ($F=39.026$, $P=0.001$).

The vertical profile of chaetognath at Stn. 11 quite resembled that at Stn. 3, but for the 505 μ mesh sample (Table 7). In 100 μ and 330 μ meshes, the abundance peaked in the 2 m layer, while it was scarce in the 0.3 m and bottom layers. The

Table 7. Abundance in weight and number of zooplankton groups collected with the NIPR net for 10 min at different depths under ice at Stn. 11, lagoon Saroma Ko, February 24, 1986.

Depth (m)	Wet weight (g)			Number	
	Copepod	Chaetognath	Amphipod	Chaetognath	Amphipod
			Mesh 100 μ		
0.3	2.92	0.06	0.08	2	2
2	2.32	1.66	0	92	0
5	1.16	0.18	0	8	0
7	2.14*	0	0	0	0
			Mesh 330 μ		
0.3	0.74	0.06	0.04	4	2
2	0.50	3.50	0	166	0
5	0.40	0.26	0	12	0
7	0.64*	0.14	<0.01	10	1
			Mesh 505 μ		
0.3	0.42	0.02	0	2	0
2	0.84	0.70	0	34	0
5	0.06	0.86	0	38	0
7	0.34*	0	0	0	0

*: Included remnants and debris of *Phyllospadix* and sand.

same profile is also traced in the depth distribution of the number. The F-value was 7.127 (P=0.022) in weight and 11.396 (P=0.008) in number, showing significant difference among depth layers. The mean value of the 2 m layer was significantly higher than those of 0.3 m ($Q=5.644>Q_{0.05,6,2}=3.461$), 5 m ($Q=3.921>Q_{0.05,6,2}=3.461$) and 7 m layers ($Q=5.657>Q_{0.05,6,3}=4.339$). Except 2 m layer, the mean value in the remaining layers did not differ from each other. Unlike copepods, the chaetognath abundance was not significantly different by mesh size in weight (F= 0.527, P=0.619) and in number (F=1.576, P=0.282).

Amphipod appeared to have existed in the entire water column with a relatively high abundance in the upper layer. However, its vertical profile was not clear due to the small sample amount.

Evidently chaetognath occurred with an extremely high abundance in 2 m layer. Despite the perceivable feature, the highest abundance with depth was not proved statistically in copepod. However, the marginal F-value suggests it is highly likely that the copepods were most abundant in the upper 2 m layers. This could be confirmed if the sample size were greater.

3.2.3. Comparison of zooplankton abundance between two stations

In vertical haul with the 100 μ mesh STD Norpac net, the copepod abundance per m³ was quite similar between Stn. 3 (0.36 g) and Stn. 11 (0.33 g) (Tables 2 and 3). Statistically there was no difference on the mean between the two stations ($F=0.489<F_{0.05,(1,4)}=7.71$, P=0.526). The comparison for 330 μ and 505 μ meshes is meaningless because of the mesh selectivity.

Of chaetognath in vertical hauls with 100 μ mesh, the mean abundance at Stn. 3 (0.30 g) was significantly lower than that at Stn. 11 (0.64 g) (F=49.409, P=0.003). Likely, chaetognath in number at Stn. 11 (28.0) was twice the number at Stn. 3 (13.03), with a highly significant difference (F=29.993, P=0.009). The same results were found in 330 μ and 505 μ meshes.

Horizontally, in comparison with the 100 μ NIPR net per 10 min filtration, the copepod abundance was higher at Stn. 11 in all the depth layers but for 5 m layer than at Stn. 3 (Tables 6 and 7). At bottom the abundance of Stn. 11 was more than 3 times that of Stn. 3. The difference at 5 m depth between the two stations was minor. When all the layers are combined, the F-value of 3.399 indicates insignificant difference between the two stations ($F_{0.05,(1,3)}=10.13$, $P=0.162$).

Chaetognath either in weight or in number appeared to be slightly higher at Stn. 11 than at Stn. 3 (Tables 6 and 7), but statistically there is no significant difference between the two stations at $\alpha=0.05$ in weight ($F=0.257$, $P=0.649$) and in number ($F=0.261$, $P=0.645$).

In summary, the comparison of abundance of copepods and chaetognath revealed contradictory results between vertical and horizontal hauls. In vertical hauls, the copepod abundance was the same between the two stations, whereas chaetognath was much more abundant at Stn. 11. In horizontal samplings, copepods were slightly abundant at Stn. 11 despite the statistical insignificance, whereas chaetognath was almost the same between the two stations.

4. Discussion

Unlike the drag of net, the filtration of plankton with the NIPR net depends entirely upon the current generated inside the net. Therefore, the water around the sampler could be under strong influence of suction and expulsion of water. Presently, the hydrodynamics of the current generated by the NIPR net, the physical process of suction of zooplankton, and from what depth layer the zooplankton are actually taken, are unknown. Conceivably, the decrease in abundance with the prolonged sampling duration in the NIPR net of 330 μ and 505 μ meshes might have been caused by the extrusion of zooplankton through net meshes with the enforced filtration pressure. It is also presumable that as the filtration time is longer, the water sucked and expelled, or formed eddies will disturb more the stability of surrounding water and spatial distribution pattern of zooplankton. This may result in the decrease of zooplankton abundance in larger meshes. Thus, it is inevitable to scrutinize the water current in a given depth layer while performing filtration by the NIPR net, and the behavioral response of zooplankters to the current, based on experimental and underwater observations.

This study proved the usefulness of the NIPR net to depict vertical stratification of zooplankton under ice. Evidently, there was uneven abundance distribution of copepods and chaetognath in water column. A similar feature has been reported in the Beaufort Sea by FUKUCHI *et al.* (1981). At a station (10 m depth), they found a peak abundance of chaetognaths under sea ice in 5 m depth layer, two times greater than the abundance in 0.5 m and bottom layers. Similarly, TANIMURA *et al.* (1984) demonstrated uneven distributions of zooplankton under ice in the Antarctic. Our results showed that chaetognath was aggregated around 2 m layer, suggesting the coincidental peak abundance with copepods. At present, it is difficult to elucidate the underlying cause of such high abundance in the upper 2 m layer. It is unlikely that the high abundance of copepods and chaetognath in the upper layer was merely an incidental phenomenon, because the observation was confirmed twice at distant locations on different dates. Although hydrographic data are lacking in the present study, it is inferred that during winter thermocline and pycnocline do not develop in the water column under ice. HOSHIAI and FUKUCHI (1981) reported the hydrographic condition at a 6 m depth station of this lagoon in early February, 1978. The vertical profiles of temperature and salinity were almost homogeneous from the surface to the bottom with $-1.3 \sim -1.5$°C and 31.09–31.93‰, respectively. Since this hydrographic condition represents a typical winter structure, our study area is assumed to have the same structure. Thus it is improbable that the anomalous hydrographic structure existed which could drive the zooplankton into the vertically stratified distribution.

There are at least two possible explanations: feeding relations and response to light condition. Abundant phytoplankton in the upper layer beneath the ice were concurrently observed in the present study (K. WATANABE, unpublished). This allows us to presume that copepods aggregated for grazing in the upper water column. Consecutively, the congregation of chaetognath might have been exerted by the occurrence of herbivores. Simply chaetognath has easy access to the copepod-abundant layer, even if it is ambush predator (FEIGENBAUM and MARIS, 1984). The gut analyses of copepods and chaetognath may partly provide answers to this assumption. Also, intensive samplings from depth layers between the surface and the 5 m depth are anticiptated to supplement a fine vertical profile of zooplankton of different trophic levels.

Another explanation is that the aggregation of copepods and chaetognath in the upper layer results from their phototactic response to the gradient of light intensity in water. Since the ice holes remained open during daytime, it is likely that the artificially induced light conditions elicit physiological or ecological response of these plankters. Copepods might have revealed a positive phototaxis and swum upward in an optimum level, while chaetognath did not migrate in the shallow layer beyond a threshold light intensity which might play as a boundary near the 2 m layer. GOTO and YOSHIDA (1981) observed positive phototactic response of *Sagitta crassa* to artificially induced horizontal light beam, and its repeated upward swimming movements with the body axis inclined toward the light source, interspersed with passive downward sinking. They concluded that the light-oriented gathering is not a simple phototaxis or photokinesis, but is mediated by photogravity and light sensing mechanism. In the future work, the measurement of the light condition in water under ice, and observations of phototactic response of zooplankton are expected.

In the vertical hauls, the sampling efficiency was the same between the STD Norpac net and the MDF Norpac net for copepods, but chaetognath was much more abundantly captured by the latter net. The cause is probably attributable to the net avoidance of chaetognath, while retrieving STD Norpac net, from the flow meter attached to the center of the net and its suspending wires, though this explanation remains to be proved in the future investigation.

5. Conclusion

The results lead us to conclude that to collect the under-ice zooplankton with the

NIPR net, the sampling with 100 μ mesh for 5-min filtration is the most appropriate in lagoon Saroma Ko. The combination of this mesh size and sampling duration will incorporate in saving the working time at station. Among three mesh sizes employed in this study, the 100 μ mesh was most efficient to obtain the zooplankton abundance. In the 330 μ and 505 μ mesh sizes, the prolongation of sampling duration over 5 min will not ensure an increase of sample amount, instead it will cause the decrease. The mesh size must be pertinent to the sizes of target species concerned to eliminate the factors of clogging, net avoidance or loss (CLUTTER and ANRAKU, 1968; VANNUCCI, 1968), and the 100 μ mesh size appears suitable so far as *Pseudocalanus* sp. is a dominant species in this lagoon. The 100 μ mesh has been frequently used for the under-ice plankton study in the Antarctic (FUKUCHI and TANIMURA, 1981; MINODA and HOSHIAI, 1982). We must be cautious about the 330 μ mesh which yields a higher variability in replicate hauls, though we were obliged to use this mesh size in this study for comparative purpose, because of its common use in the quantitative study of zooplankton in the subarctic North Pacific waters (*e.g.* MORIOKA, 1972; HATTORI and MOTODA, 1983) and shallow bay (MORIOKA, 1981). The abundance and species composition of zooplankton under ice must be examined on intermediate mesh sizes between 100 μ and 330 μ meshes in the future study.

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References

CLUTTER, R. I. and ANRAKU, M. (1968): Avoidance of samplers. Zooplankton Sampling, Paris, The Unesco Press, 57–76 (Monographs on Oceanographic Methodology 2).

FEIGENBAUM, D. L. and MARIS, R. C. (1984): Feeding in the chaetognatha. Oceanogr. Mar. Biol. Ann. Rev., **22**, 343–392.

FUKUCHI, M. (1982): Dôbutsu Purankuton (Zooplankton). Nankyoku no Kagaku, 7. Seibutsu (Science in Antarctica, 7. Biology), ed. by Natl Inst. Polar Res. Tokyo, Kokon Shoin, 96–114.

FUKUCHI, M. and SASAKI, H. (1981): Phytoplankton and zooplankton standing stocks and downward flux of particulate material around fast ice edge of Lützow-Holm Bay, Antarctica. Mem. Natl Inst. Polar Res., Ser. E (Biol. Med. Sci.), **34**, 13–36.

FUKUCHI, M. and TANIMURA, T. (1981): A preliminary note on the occurrence of copepods under sea ice near Syowa Station, Antarctica. Mem. Natl Inst. Polar Res., Ser. E (Biol. Med. Sci.), **34**, 37–43.

FUKUCHI, M., TANIMURA, A. and HOSHIAI, T. (1979): "NIPR-I", a new plankton sampler under sea ice. Nihon Purankuton Gakkai Hô (Bull. Plankton Soc. Jpn.), **26**, 104–109.

FUKUCHI, M., ALEXANDER, V. and HOSHIAI, T. (1981): Vertical distribution of zooplankton under the sea ice in Prudhoe Bay, Arctic. Abstract presented at the Annual Meeting of the Plankton

Society of Japan, April. Tokyo.

GOTO, T. and YOSHIDA, S. (1981): Oriented light reactions of the arrow worm *Sagitta crassa* Tokioka. Biol. Bull., **160**, 419–430.

HATTORI, H. and MOTODA, S. (1983): Regional difference in population communities in the western North Pacific Ocean (CSK Data). Nihon Purankuton Gakkai Hô (Bull. Plankton Soc. Jpn.), **30**, 53–63.

HOSHIAI, T. and FUKUCHI, M. (1981): Sea ice colored by ice algae in a lagoon, Lake Saroma, Hokkaido, Japan. Nankyoku Shiryô (Antarct. Rec.), **71**, 113–120.

KIKUCHI, K., NOZAWA, Y. and MATSUMOTO, E. (1984): Taiseki-butsu kara mita Saroma Ko no kankyô henka ni tsuite (Environmental changes of Lake Saroma recorded in sediment cores). Hokkaido Suisan Shihô (Sci. Rep. Hokkaido Fish. Exp. Stn.), **26**, 11–24.

MINODA, T. and HOSHIAI, T. (1982): Zooplankton community in the cove of Cumberland Bay, South Georgia, in the southern summer from January to February 1973. Mem. Natl Inst. Polar Res., Spec. Issue, **23**, 32–37.

MORIOKA, Y. (1972): The vertical distribution of Calanoid copepods off the southeast coast of Hokkaido. Biological Oceanography of the Northern North Pacific Ocean, ed. by A. Y. TAKENOUTI *et al.* Tokyo, Idemitsu Shoten, 309–321.

MORIOKA, Y. (1981): Zooplankton production in the Toyama Bay in March–May, 1978. Nihonkai-ku Suisan Kenkyûjo Kenkyû Hôkoku (Bull. Jpn. Sea Reg. Fish. Res. Lab.), **32**, 57–64.

MORIOKA, Y. and KOMAKI, Y. (1977): Mesh width and porosity of plankton filtering gauges. Nihon-kai-ku Suisan Kenkyûjo Kenkyû Hôkoku (Bull. Jpn. Sea Reg. Fish. Res. Lab.), **28**, 59–62.

MOTODA, S. (1957): North Pacific Standard Plankton net. Inf. Bull. Planktol. Jpn., **4**, 13–15.

TANIMURA, A., MINODA, T., FUKUCHI, M., HOSHIAI, T. and OHTSUKA, H. (1984): Swarm of *Paralabidocera antarctica* (Calanoida, Copepoda) under sea ice near Syowa Station, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **82**, 12–19.

VANNUCCI, M. (1968). Loss of organisms through the meshes. Zooplankton Sampling, Paris, The Unesco Press, 77–86 (Monographs on Oceanographic Methodology 2).

ZAHR, J. H. (1974): Biostatistical Analysis. Englewood Cliffs, Prentice-Hall, 620 p.

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