Bull. Fish. Sci. Hokkaido Univ.
57(3), 25–35, 2007.

Food Availability for First-feeding Walleye Pollock (*Theragra chalcogramma*) Larvae during Winter in and Near Funka Bay, Hokkaido, Japan, as Inferred from Copepod Nauplii Abundance

Toshikuni NAKATANI[†1], Masakane OHSHIMA[1], Kie YOSHIDA[2], Shiho SASAKI[2], Norihiro SHIRAKAWA[2] and Naohiro YAMAMOTO[2]

(Received 26 September 2006, Accepted 2 February 2007)

Abstract

To clarify the relationship between the food availability for pollock larvae and the hydrographic conditions in Funka Bay, horizontal distributions of water temperature, salinity and *Oithona* nauplii (main food for larval pollock) were investigated in winter from 2001 to 2003 in and near the bay. In January 2001 and 2003, the Oyashio coastal cold-water mass and the Tsugaru warm-water mass were co-distributed in the bay and its mouth region, but in January 2002, the Oyashio coastal cold-water mass has already exchanged with the Tsugaru warm-water mass. The median abundances of *Oithona* nauplii in January of each year were not different significantly. In January 2003, the density of female *O. similis* (main producer of *Oithona* nauplii) was higher in the Oyashio coastal cold-water mass than in the Tsugaru warm-water mass, while the densities of *Oithona* N1 in the Oyashio coastal cold-water mass and the Tsugaru marm-water mass were almost identical. These data indicate that the high activity of the individual reproduction is occurred in the Tsugaru warm water. From the results, it is considered that the warm-water temperature and the reproduction of *O. similis* in the Tsugaru warm-water mass in winter in Funka Bay support the larval feeding success.

Key words: *Oithona similis*, *Oithona* nauplii, Reproduction, Food conditions, First-feeding walleye pollock, *Theragra chalcogramma*, Larvae, Funka Bay, Hokkaido, Japan

Introduction

Funka Bay (Hokkaido, Japan) is a major nursery ground of walleye pollock, *Theragra chalcogramma* around Japan (e.g. Nakatani and Maeda, 1989). The population of pollock is distributed from Hokkaido Island to northern Honshu Island (Tohoku area) (Fig. 1). The spawning ground of this population was found from the mouth of Funka Bay and its northeastern side (Nakatani and Maeda, 1981; 1989). In general, spawning occurs from December to March (Maeda et al., 1979, 1980; Yoon, 1981). Eggs are transported into the bay by eddies generated by the combination of the predominant northwesterly winds in winter and the parabolic bottom topography of the bay (Shimizu and Isoda, 1997). Many eggs hatch in the center of the bay, and newly hatched larvae (smaller than 7 mm in total length) initiate feeding on nauplii of cyclopoid copepod *Oithona* (Nakatani, 1995a; Sasaki, unpublished data).

The Tsushima Warm Current flows along Honshu Island, and its major outflow from the Sea of Japan occurs through the Tsugaru Strait to the Pacific Ocean (Fig. 1A). This water, named the Tsugaru warm-water mass (TWW; ≧33.8 PSU; Ohtani, 1971) enters Funka Bay in late summer and/or autumn and occupies the whole bay through winter (Fig. 1B). From January to February, the Oyashio coastal cold-water mass (OCCW; 33.0–33.3 PSU; Ohtani, 1971) enters the bay (Fig. 1C), and the TWW replaces by the OCCW. The copepod community in the bay, which dominates the mesozooplankton, varies in accordance with the intrusions of the two water masses (Hirakawa and Kawamura, unpublished data). The preliminary study on the population dynamics of copepod nauplii shows that the density of copepod nauplii was almost identical in the two water masses in winter (Nakatani and Maeda, 1989).

In Funka Bay, *Oithona similis* is the dominant copepod, accounting for more than 80% of the total number of Oithonids, and reproduces throughout the year (e.g. Itoh et al., unpublished data). They also dominate the assembly of copepod nauplii during winter and the naupliar abundance of other copepods such as

[1] *Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan*
[2] *Faculty of Fisheries, Hokkaido University, 3-1-1 Minato, Hakodate, Hokkaido 041-8611, Japan*
[†] nakatani@fish.hokudai.ac.jp

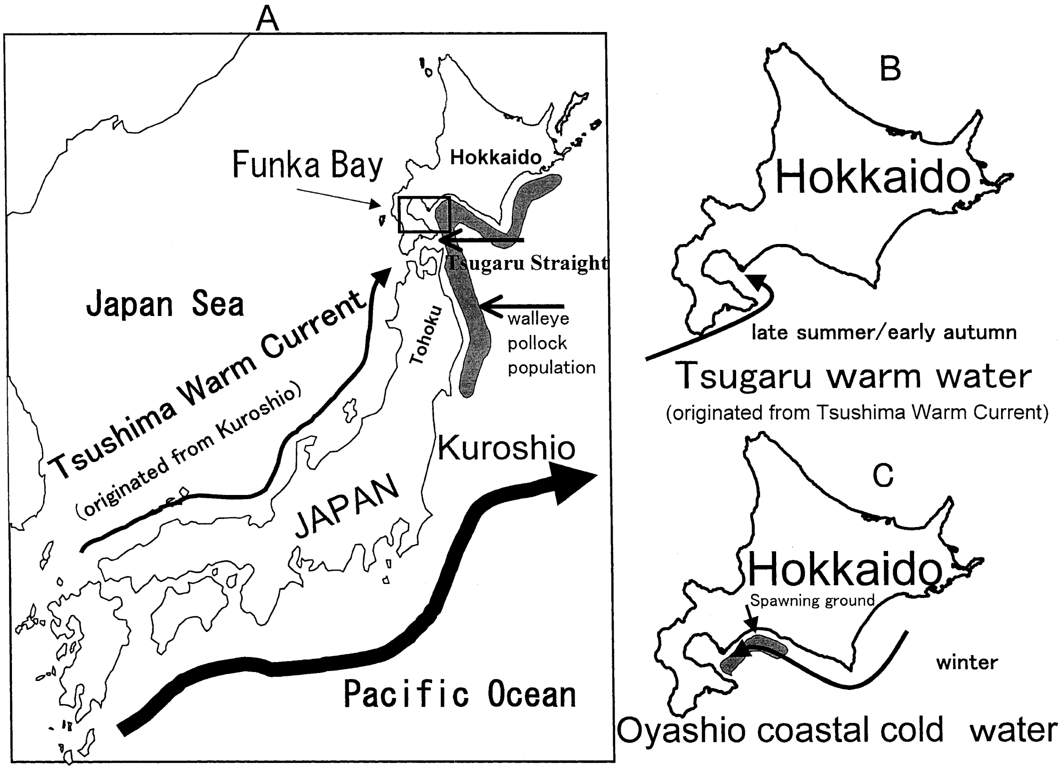

Fig. 1. Oceanic circulation around the Japanese Islands (A), and hydrographic conditions during summer (B) and winter (C) in Funka Bay and adjacent waters.

Pseudocalanus nauplii does not increase until the intrusion of the OCCW (Nakatani, 1995b, Sugimoto, unpublished data).

In recent years, newly hatched larvae of walleye pollock have been found in the center of Funka Bay with large interannual variations in abundance (Nakatani et al., 2003a). The density of copepod nauplii had been investigated from 1991 to 1999 to assess the food availability of first-feeding larvae, but these samplings were conducted at only a few stations in a restricted area of the bay, and no information was obtained concerning the relationship between the geographic distribution of *Oithona* nauplii and hydrographic conditions. It is supposed that both the TWW population and the OCCW population of *O. similis* co-occur in Funka Bay in early winter and that the reproduction of this species controls the food availability for first-feeding larval pollock. However, the density and distribution of female *O. similis* and their newly hatched nauplii (N1 stage) in the TWW and the OCCW is unknown. In this study, we observed the distribution of female *O. similis*, *Oithona* N1 and pollock larvae in and near Funka Bay in winter to understand the food availability of the first-feeding larvae in relation to the geographic distribution of the two water masses.

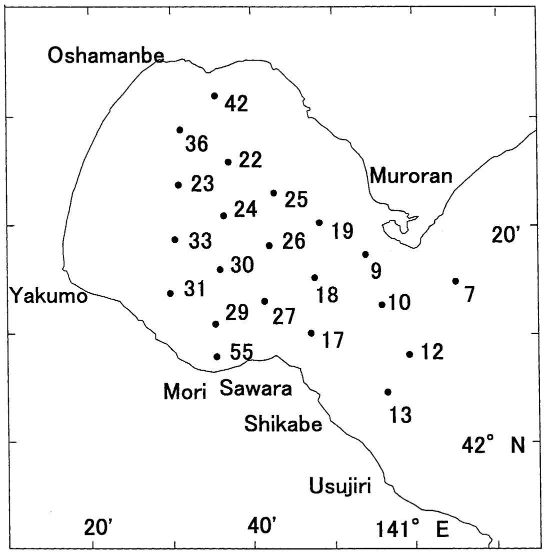

Fig. 2. Sampling stations in Funka Bay and adjacent waters.

Materials and Methods

Daytime sampling was conducted during winter (January, February, and March) from 2001 to 2003 by the R/V *Ushio Maru* and T/S *Oshoro Maru* of the Faculty of Fisheries, Hokkaido University (Fig. 2). Earlier studies have shown that pollock larvae are mainly distributed at

0–30 m depth (Kamba, 1977 ; Nakatani, 1988), and most pollock larvae collected by a plankton net in January and February are at the first feeding stage (<7 mm in total length ; Nakatani et al., 2003a). Before the intrusion of the OCCW in January, vertically homogenous hydrographic conditions are observed in Funka Bay (e.g. Nakatani et. al., 2003b). In mid winter, the OCCW enters the surface layer of the bay. In addition, a homogeneous distribution of copepod nauplii has been observed at 0–30 m depth in this area in winter (Ohshima, unpublished data). Therefore, copepod nauplii were collected at the surface layer (15 m depth) with a 20 L Van Dorn water sampler to assess the food availability of first-feeding larval pollock. Water samples were filtered through a 40 μm mesh sieve, and retained plankton were preserved in 5% buffered formalin seawater. *Oithona* nauplii were sorted by developmental stage under a light microscope according to Gibbons and Ogilvie (1933). Pollock larvae were collected by vertical hauls from the sea bottom to the surface with a plankton net (80 cm mouth diameter ; 0.33 mm mesh size). Samples were immediately preserved with 5% buffered formalin seawater. In winter 2003, *O. similis* copepodids were collected by vertical hauls from the sea-bottom to the surface with a plankton net (45 cm diameter ; 0.1 mm mesh size). These samples were sorted from Stage C1 to C6 according to Uchima (1979). At all stations, water temperature and salinity from the surface to the sea bottom were measured with a CTD (model SBE, Seabird Co., Ltd.). Mann-Whitney U-tests were used for non-parametrical comparison of medians of samples between two water masses (TWW and OCCW), and the Kruskal-Wallis test and Steel-Dwass test were used for multiple comparisons.

Results

Hydrographic conditions

In January 2001, the OCCW (<33.4 PSU) was observed in the northeastern side of the bay at 15 m depth, and the TWW (>33.6 PSU) occupied the inner area of the bay (Fig. 3). The front between the TWW and the OCCW stretched from the southwestern bay mouth to the center of the bay. The water temperature of the TWW in the center of the bay ranged from 4.5 to 5.0°C. In contrast, the water of the eastern area of the front (OCCW) was below 3°C. In January 2002, the OCCW occupied most in the bay (2.0–4.0°C), except off Sawara (4°C, 33.4 PSU). In January 2003, the TWW (≧33.4

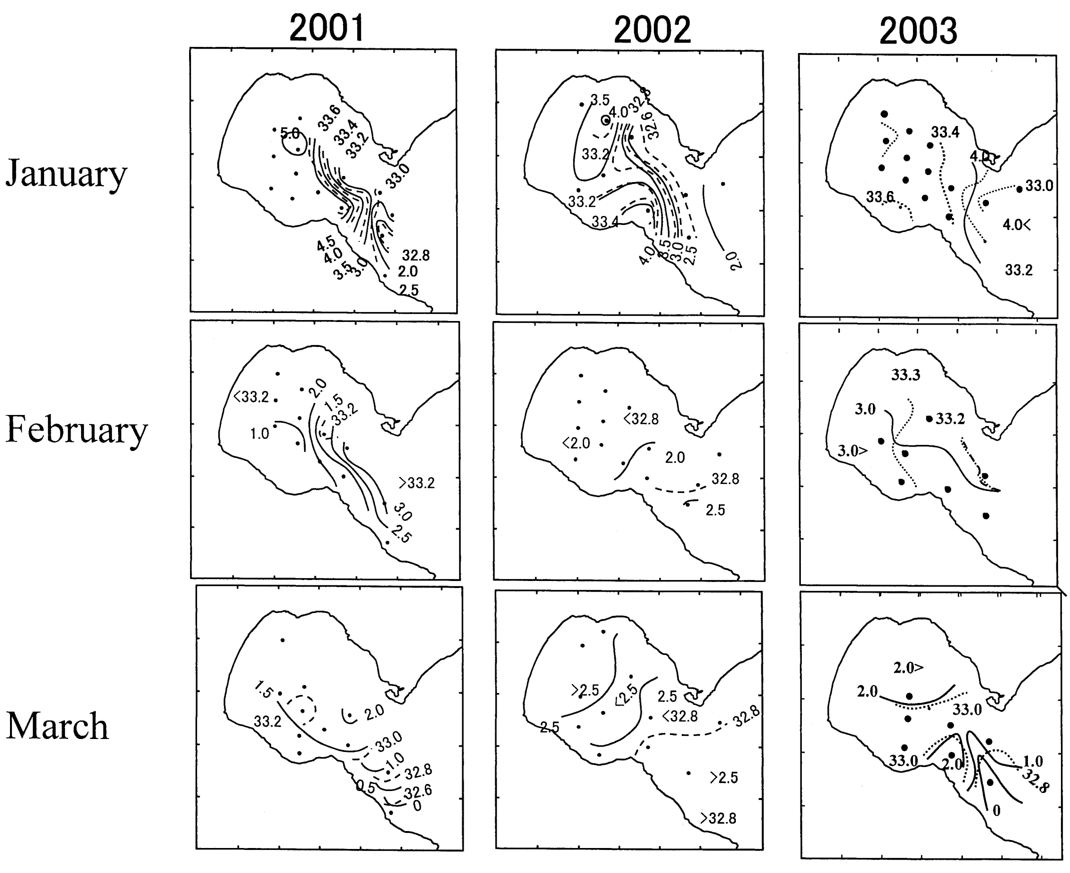

Fig. 3. Distribution of water temperature (°C, ——) and salinity (PSU, -----) at 15 m depth in winter from 2001 to 2003.

PSU) was distributed in the center of the bay. The water temperature was warmer than 4°C. On the other hand, the OCCW (≦33.2 PSU) occupied the bay mouth. In this area, the water temperature was below 4°C. Vertical profiles of temperature and salinity at Station 7 (out side the bay) showed that the OCCW (≦ 33.2 PSU) occurred throughout the water column and the water temperature at 0–50 m depth was less than 4.0°C (Fig. 4). At Station 30, the TWW (≧33.4 PSU) was occupied from the surface to the sea bottom.

In February 2001, the OCCW filled the bay (1.0–3.0°C). The hydrographic conditions were comparable to those in February 2002 (2.0–2.5°C) and 2003 (*ca* 3.0°C).

In March 2001, the water temperature of the OCCW decreased to 0–1.5°C. Very cold water (<0°C) was observed at the coastal site off Usujiri in 2001 and 2003, while the water temperature of the OCCW in March 2002 (*ca.* 2.5°C) was warmer than those in March 2001 and 2003 (0–2.0°C).

Density and developmental stage composition of O. similis

Fig. 5 indicates the developmental stage composition of *O. similis* collected inside (Station 30) and outside (Stations 7 and 10) of the bay from January to March 2003. In the bay, the developmental stage composition between January and February did not differ statistically ($KW'=0.364$, $p=0.546$), but females decreased significantly in abundance from February to March ($KW'=4.235$, $p=0.040$). The developmental stage comparison between inside and outside the bay did not differ from January to March ($KW'=0.381$–3.712, $p=0.054$–0.537). The developmental stage composition of *O. similis* outside the bay was identical from January to March ($KW'=0.002$–1.215, $p=0.270$–0.963). As shown in Figs. 4 and 5, many females *O. similis* were collected at Station 7 (616.0 individuals•m^{-3}, in the OCCW (32.9– 33.2 PSU)) in January, while the density of females was as low as 273.6 individuals•m^{-3} at Station 30 (in the TWW (33.5–33.6 PSU)). Then the density of females at both stations decreased after the intrusion of the OCCW in February (144.5–273.3 individuals•m^{-3}) and increased in March (310.6–587.9 individuals•m^{-3}).

Distribution of Oithona nauplii

In January 2001, 76.5–90.5% of copepod nauplii were *Oithona* (Table 1). The minimum density of *Oithona* nauplii was observed outside the bay in the OCCW (Station 13, 4.1 individuals•L^{-1}), while the density of *Oithona* nauplii in the center of the bay ranged from 4.5 to 8.4 individuals•L^{-1}. The dominance of *Oithona* nauplii was also observed in February, but decreased slightly. Outside the bay (Stations 13 and 17), the densities were as low as 1.1–2.6 individuals•L^{-1}, while high densities of *Oithona* nauplii were observed in the center of the bay (4.3–6.5 individuals•L^{-1}). In March, 41.5–74.6% of copepod nauplii were *Oithona*. The density of *Oithona* nauplii increased from February to March, especially at Station 13 (9.4 individuals•L^{-1}) and Station 18 (9.4 individuals•L^{-1}). Densities of other genera also increased.

In January 2002, 64.0–82.7% of copepod nauplii were *Oithona* (Table 2). In February, *Oithona* nauplii were distributed widely at all stations (4.3–8.9 individuals•L^{-1}). *Oithona* nauplii still dominated (68.5–96.2%) except at Station 25 (45.9%) and Station 31 (54.8%). In March, *Pseudocalanus* nauplii dominated (43.5–72.1%),

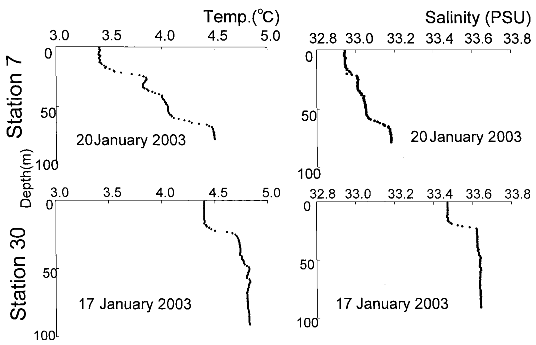

Fig. 4. Vertical profile of water temperature (°C, left panels) and salinity (PSU, right panels) at Station 7 (upper panels) and Station 30 (bottom panels) in January 2003.

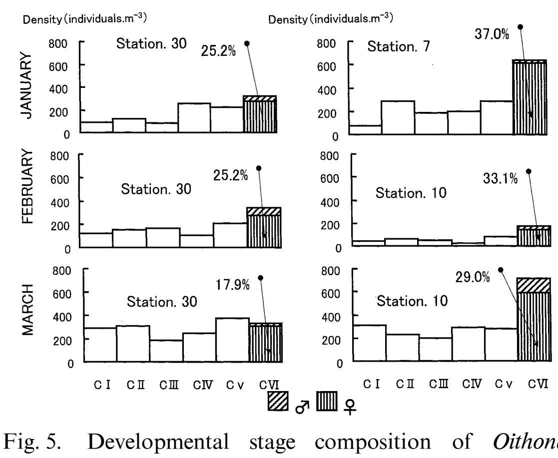

Fig. 5. Developmental stage composition of *Oithona similis* copepodids in (Station 30 ; left panels) and outside (Stations 7 and 10 ; right panels) of Funka Bay. Samples were collected by vertical hauls from near bottom to the surface with a plankton net (0.45 m in diameter, 0.1 mm mesh size) in January 2003.

Table 1 Density of copepod nauplii (indivs.•L^{-1}) from January to March in 2001. Samples were collected at 15 m depth.

17–19 January								
	St. 13	St. 17	St. 18	St. 23	St. 25	St. 30	St. 31	St. 36
Oithona	4.10	5.60	4.60	8.40	7.60	4.50	5.20	6.30
Pseudocalanus	0.60	0.00	0.70	0.00	0.40	0.00	0.00	0.30
Acartia	0.20	0.40	0.10	0.60	0.00	0.00	0.20	0.10
※ *P & C*	0.20	0.10	0.00	1.00	0.30	0.50	1.10	0.70
Corycaeus	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.40
Oncaea	0.00	0.00	0.00	0.20	0.00	0.00	0.10	0.20
Microcalanus	0.00	0.10	0.00	0.20	0.10	0.00	0.00	0.00
Mesocalanus	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Calanus	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10
Microsetella	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
unidentified nauplii	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00
total	5.10	6.20	5.70	10.60	8.40	5.00	6.80	8.10

15–16 February								
	St. 13	St. 17	St. 22	St. 23	St. 24	St. 30	St. 33	St. 36
Oithona	2.55	1.10	6.50	4.30	6.30	6.00	6.40	4.30
Pseudocalanus	0.30	0.50	2.00	1.40	2.40	1.70	1.70	0.85
Acartia	0.00	0.00	0.00	0.30	0.10	0.10	0.10	0.20
※ *P & C*	0.20	0.00	0.00	0.00	0.00	0.10	0.00	0.10
Oncaea	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Microcalanus	0.00	0.00	0.00	0.10	0.00	0.00	0.20	0.00
Mesocalanus	0.15	0.00	0.20	0.10	0.00	0.30	0.10	0.00
Calanus	0.00	0.00	0.10	0.00	0.10	0.00	0.10	0.00
Metridia	0.00	0.00	0.00	0.20	0.00	0.00	0.20	0.20
Tortanus	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
unidentified nauplii	0.05	0.00	0.00	0.00	0.00	0.10	0.00	0.10
total	3.25	1.65	8.80	6.40	8.90	8.30	8.90	5.75

13–15 March									
	St. 13	St. 17	St. 18	St. 24	St. 27	St. 29	St. 30	St. 33	St. 36
Oithona	9.40	5.20	9.40	6.20	5.77	6.20	3.98	6.20	8.29
Pseudocalanus	9.80	2.20	2.80	5.00	3.30	3.60	3.75	1.80	5.15
Acartia	1.80	0.50	0.40	0.40	0.93	1.80	1.87	2.60	0.86
Mesocalanus	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calanus	0.20	0.00	0.00	0.00	0.21	0.20	0.00	0.00	0.00
Metridia	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
unidentified nauplii	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
total	22.00	7.90	12.60	12.00	10.20	11.80	9.60	10.60	14.30

※ *P & C : Paracalanus and Clausocalanus*

Table 2 Density of copepod nauplii (indivs.・L^{-1}) from January to March in 2002. Samples were collected at 15 m depth.

23–25 January						
	St. 7	St. 10	St. 13	St. 17	St. 22	St. 31
Oithona	6.50	7.93	7.72	3.61	8.40	3.79
Pseudocalanus	3.46	2.24	3.86	0.72	1.36	1.26
Acartia	0.20	0.20	0.20	0.18	0.14	0.18
Calanus	0.00	0.61	0.61	0.09	0.00	0.00
Metridia	0.00	0.00	0.00	0.00	0.00	0.09
Oncaea	0.00	0.00	0.00	0.00	0.27	0.00
Centropages	0.00	0.20	0.00	0.00	0.00	0.00
total	10.16	11.18	12.40	4.61	10.16	5.33

13–15 February											
	St. 7	St. 12	St. 13	St. 17	St. 18	St. 22	St. 23	St. 25	St. 27	St. 31	St. 33
Oithona	8.54	4.34	4.88	4.61	8.94	6.71	3.76	5.69	7.32	4.72	7.52
Pseudocalanus	2.03	0.54	0.20	0.18	3.66	1.52	1.32	6.71	1.95	3.74	3.25
Acartia	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Calanus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Metridia	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.16	0.16	0.00
Oncaea	0.20	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	10.77	4.88	5.18	4.79	12.60	8.43	5.08	12.40	9.43	8.62	10.98

12–14 March								
	St. 7	St. 13	St. 17	St. 18	St. 30	St. 31	St. 33	St. 55
Oithona	6.50	6.78	7.59	27.64	8.13	4.34	4.88	5.28
Pseudocalanus	24.39	6.50	19.51	30.08	28.46	8.40	35.77	20.33
Acartia	2.85	0.00	0.00	8.13	1.63	0.00	1.63	1.22
Calanus	0.41	0.54	0.00	0.81	1.63	0.00	2.44	0.00
Metridia	0.41	0.00	0.54	0.00	0.00	0.00	4.07	0.00
※ *P & C*	2.03	0.00	0.54	2.44	0.00	0.54	0.00	0.41
Microsetella	0.00	1.08	0.54	0.00	0.81	0.27	0.81	1.22
total	36.59	14.91	28.73	69.11	40.65	13.55	49.59	28.46

※ *P & C : Paracalanus and Clausocalanus*

followed by *Oithona* nauplii (9.8–45.5%). The density of *Oithona* nauplii (4.3–8.1 individuals・L^{-1}) changed little from February except at the mouth of the bay (Station 18 ; 27.6 individuals・L^{-1}).

In January 2003, the density of *Oithona* nauplii ranged from 2.6 to 5.7 individuals・L^{-1} in the TWW and from 3.1 to 5.9 individuals・L^{-1} in the OCCW (Table 3). In February the density ranged from 1.8 to 5.4 in the OCCW. In March, the density increased, especially in the center of the bay mouth. The density median of *Oithona* nauplii was lower in January 2003 (3.54 individuals・L^{-1}) than in 2001 and 2002 (5.40–6.86 individuals・L^{-1}, $KW'=9.52$, $p=0.009$; Steel–Dwass test, $p<0.05$).

Distribution of Oithona N1

To investigate the reproduction activity of *Oithona* geographically, *Oithona* N1 were collected in winter from 2001 to 2003 in and near Funka Bay and the mouth area (Fig. 6). In January 2001, the density of *Oithona* N1 ranged from 0.8 to 2.6 individuals・L^{-1} in the center of the bay, and none were collected outside the bay in the OCCW (Station 13). The maximum density of *Oithona* N1 was observed at the center of the

Table 3　Density of copepod nauplii (indivs.•L^{-1}) from January to March in 2003. Samples were collected at 15 m depth.

17–20 January	St. 7	St. 10	St. 17	St. 18	St. 22	St. 23	St. 24	St. 25	St. 26	St. 27	St. 29	St. 30	St. 33	St. 36
Oithona	3.11	4.02	3.41	5.92	3.09	4.81	5.36	3.00	4.26	5.67	3.00	3.67	2.71	2.56
Pseudocalanus	0.51	0.95	0.37	0.58	0.21	0.40	0.61	0.63	0.30	0.78	0.43	0.81	0.54	0.24
Acartia	0.06	0.21	0.09	0.58	0.21	0.40	1.07	0.14	0.30	0.44	0.92	0.31	0.18	0.06
Oncaea	0.06	0.11	0.09	0.00	0.00	0.00	0.00	0.14	0.00	0.11	0.00	0.20	0.00	0.12
Calanus	0.00	0.00	0.09	0.00	0.00	0.08	0.31	0.21	0.20	0.11	0.18	0.10	0.18	0.06
Mesocalanus	0.00	0.11	0.00	0.00	0.10	0.08	0.00	0.14	0.00	0.11	0.00	0.00	0.09	0.00
Metridia	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.06	0.31	0.00	0.00
Paracalanus	0.00	0.11	0.00	0.00	0.00	0.00	0.15	0.00	0.20	0.11	0.06	0.10	0.00	0.00
Corycaeus	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.10	0.11	0.00	0.00	0.00	0.00
Tortanus	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microsetella	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
total	3.75	5.50	4.05	7.15	3.60	5.85	7.65	4.25	5.35	7.45	4.65	5.60	3.70	3.05

17–19 February	St. 10	St. 13	St. 25	St. 29	St. 33
Oithona	3.30	1.80	3.77	5.36	4.23
Pseudocalanus	1.65	0.40	1.43	1.27	0.68
Acartia	1.24	0.05	0.13	0.28	0.41
Calanus	0.41	0.00	0.26	0.14	0.27
Mesocalanus	0.41	0.00	0.00	0.00	0.00
Metridia	0.14	0.00	0.13	0.00	0.00
Paracalanus	0.00	0.00	0.13	0.00	0.00
Corycaeus	0.00	0.00	0.00	0.14	0.00
total	7.15	2.25	5.85	7.20	5.60

13–15 March	St. 10	St. 13	St. 18	St. 24
Oithona	4.58	8.60	8.03	4.27
Pseudocalanus	3.77	2.50	9.51	3.64
Acartia	3.77	0.55	0.42	2.21
Oncaea	0.00	0.00	0.00	0.16
Calanus	0.81	0.28	0.21	0.47
Mesocalanus	0.54	0.00	0.42	0.00
Metridia	0.27	0.00	0.00	0.32
Paracalanus	0.00	0.28	0.00	0.63
total	13.75	12.20	18.60	11.70

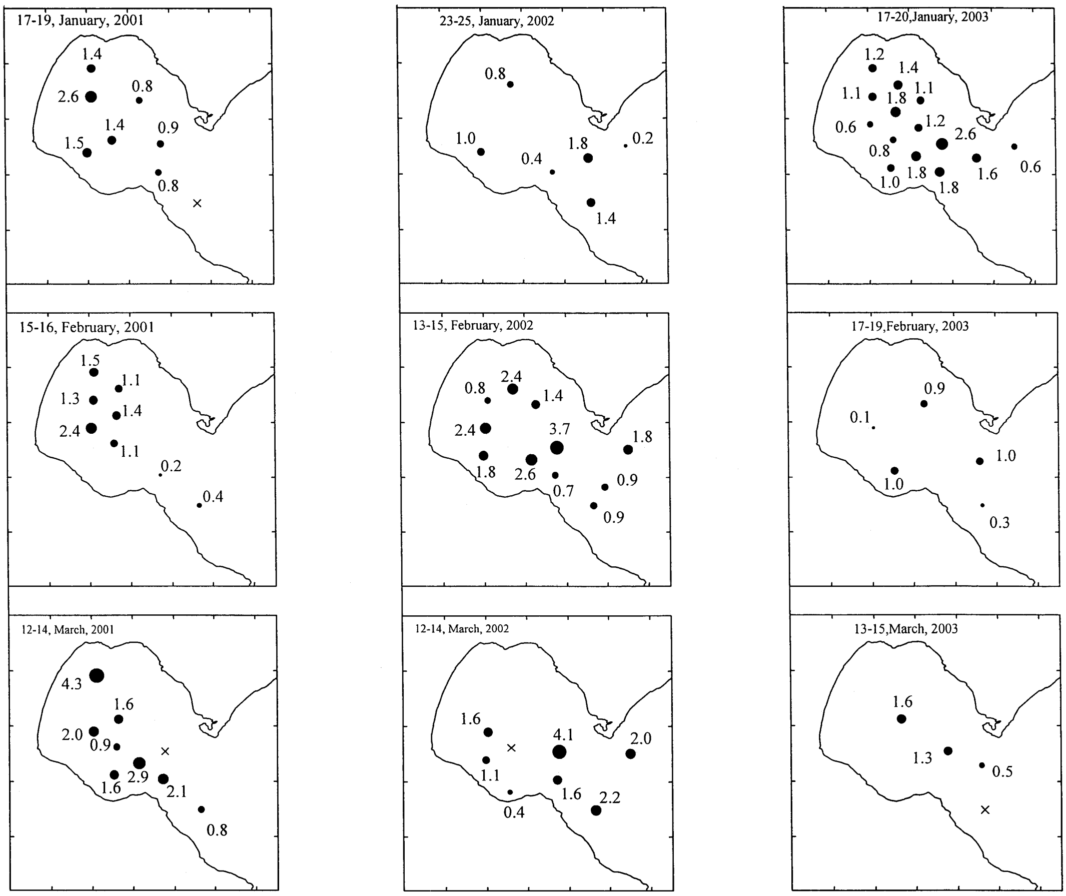

Fig. 6. Distribution of *Oithona* N1 collected at 15 m depth during winter from 2001 to 2003.

bay (Station 23 ; 2.6 individuals$\cdot$L^{-1}). In February, low densities of *Oithona* N1 were observed outside the bay (Stations 13 and 17 ; 0.2–0.4 individuals$\cdot$L^{-1}). In contrast, the density of *Oithona* N1 in the center of the bay ranged from 1.1 to 2.4 individuals$\cdot$L^{-1}. The density of *Oithona* N1 in March increased from 0.8 to 4.3 individuals$\cdot$L^{-1} except at Station 18 where *Oithona* N1 were not collected. The maximum density was observed at the center of the bay (Station 23 ; 4.3 individuals$\cdot$L^{-1}).

In January 2002, the density of *Oithona* N1 ranged from 0.2 to 1.8 individuals$\cdot$L^{-1}, and the minimum density was observed off Muroran (Station 7 ; 0.2 individuals$\cdot$L^{-1}). In February, *Oithona* N1 were abundant in the center of the bay (0.7–3.7 individuals$\cdot$L^{-1}). The abundance of *Oithona* N1 increased in March, and the maximum density was observed at the mouth of the bay (Station 18 ; 4.1 individuals$\cdot$L^{-1}). The densities of four stations in the center of the bay (Stations 30, 31, 33, and 55) were as low as 0–1.6 individuals$\cdot$L^{-1}.

In January 2003, the density of *Oithona* N1 ranged from 0.6 to 1.8 individuals$\cdot$L^{-1} in the TWW (>33.4 PSU) and from 0.6 to 2.6 individuals$\cdot$L^{-1} in the OCCW (33.0–33.4 PSU) (Figs. 3 and 6). Densities in the TWW and the OCCW did not differ significantly (Us$=$26, $p>0.20$). In the bay (Station 30), 0.80 N1$\cdot$L^{-1} were collected, while 0.57 N1$\cdot$L^{-1} were collected outside the bay (Station 7). The density of *Oithona* N1 ranged from 0.1 to 1.0 individuals$\cdot$L^{-1} in February and from 0 to 1.6 individuals$\cdot$L^{-1} in March.

From 2001 to 2003, the medians of *Oithona* N1 in January were not different statistically ($KW'=1.85$, $p=0.40$).

Distribution of walleye pollock larvae

In winter 2001, many larvae were collected in January, with a maximum of 718.2 individuals$\cdot$m^{-2} off Mori (Station 29 ; Table 4). The density of larvae in the inner area of the bay ranged from 9.9 to 718.2 individuals$\cdot$m^{-2}. The densities of larval pollock were much lower in the OCCW (0–17.9 individuals$\cdot$m^{-2}) than in the center of the bay. The densities of pollock larvae were higher in the TWW than in the OCCW (Us$=$70.0, $p<0.001$). In January 2003, many larvae were also collected in the TWW in the center of the bay, although we could not compare the abundances statistically because only two stations (Stations 7 and 10) in the OCCW were observed (Table 4, Fig. 7). In contrast,

Table 4 Individual number per square meter of walleye pollock larvae collected by vertical hauls from the sea bottom to the surface with a plankton net (80 cm diameter, mesh size=0.33 mm) durring winter season from 2001 to 2003

Station	7	9	10	12	13	17	18	19	22	23	24	25	26	27	29	30	31	33	36	42	55
2001, Jan., 17–19	—	6.0	0.0	2.0	17.9	415.8	99.5	9.9	449.6	407.8	704.3	210.9	—	230.8	718.2	228.8	549.1	435.7	461.5	—	—
2001, Feb., 15–16	—	—	—	—	0.0	89.5	163.1	—	314.3	33.8	159.2	—	87.5	165.1	—	314.3	—	33.8	258.6	—	—
2001, Mar., 12–14	—	—	—	—	41.8	85.5	8.0	—	—	—	43.8	—	—	75.6	73.6	35.8	—	107.4	23.9	—	—
2002, Jan., 23–25	0.0	—	0.0	—	11.9	2.0	—	—	4.0	—	—	4.0	—	—	—	0.0	2.0	—	2.0	—	—
2002, Feb., 13–15	6.0	—	—	2.0	8.0	2.0	0.0	—	0.0	0.0	0.0	2.0	—	2.0	—	2.0	35.8	13.9	0.0	—	—
2002, Mar., 12–14	8.0	—	—	—	8.0	8.0	0.0	—	—	—	—	10.0	—	—	—	4.0	4.0	4.0	0.0	0.0	2.0
2003, Jan., 17–20	2.0	—	4.5	—	11.6	15.1	17.6	—	15.6	13.6	8.0	6.5	10.6	32.7	40.2	31.1	—	24.6	21.6	—	—
2003, Feb., 17–19	—	—	3.0	—	25.1	55.3	—	—	—	—	—	3.5	—	—	57.3	28.1	—	18.6	—	—	—
2003, Mar., 13–15	—	—	1.0	—	0.0	2.5	1.0	—	—	—	1.5	—	0.0	—	5.5	5.0	—	—	—	—	—

—: No Data

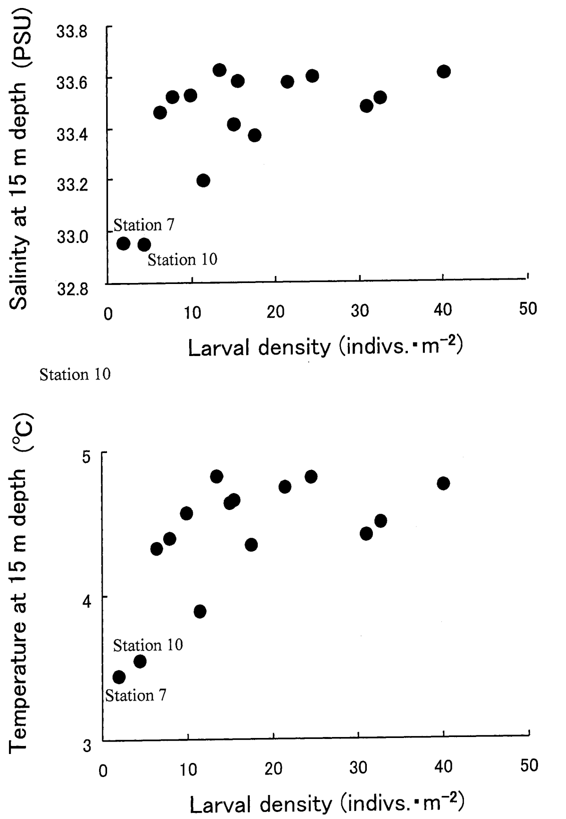

Fig. 7. Relationship between density of walleye pollock larvae and salinity (upper panels) and temperature (lower panel). Samples were collected by vertical hauls with a plankton net (80 cm diameter, 0.33 mm mesh size) from 17 to 20 in January 2003.

early intrusion of the OCCW was observed in January 2002 and small numbers of larval pollock were found in the bay and the mouth region. From February to March in three years, the larval densities gradually decreased.

The medians of pollock larvae in January were different statistically ($KW'=18.4$, $p<0.001$; Steel-Dwass test, 2001 vs. 2002, $p<0.01$, 2001 vs. 2003 $p<0.05$, and 2002 vs. 2003, $p<0.01$).

Discussion

Oithona nauplii, which are the main food of first-feeding pollock larvae in Funka bay (Nakatani, 1995b; Sasaki, unpublished data), dominate the assemblage of copepod nauplii in winter in the bay (e.g. Nakatani, 1995a; Tables 1-3). Nakatani, et al. (2003b) found that the *O. similis* population is transported into the bay by the TWW in late summer and remains in Funka Bay and its adjacent waters until the intrusion of the OCCW. During the three winters of this study, the *Oithona* nauplii TWW population was distributed only in the center of the bay in January 2001 and 2003 (Fig. 3, Tables 1-3). In this area, water temperature was as high as 4.0-5.0℃, and first-feeding pollock larvae were concentrated in the same area. In January 2003, the density of *O. similis* in the TWW (Station 30) was lower than that in the OCCW (Station 7) (Table 4). However, the density of *Oithona* N1 was a little higher in the TWW than in the OCCW. In comparison to January 2001 and 2003, the OCCW already occupied the whole area of the bay in January 2002. At this time, *Oithona* nauplii were widely distributed at all sampling stations (Table 2) and the medians of *Oithona* N1 in January 2001, 2002, and 2003 did not differ statistically (KW′= 1.85, $p=0.40$). Sabatini and Kiørboe (1994) found that *Oithona* spp. production during winter at Kattegat, Denmark was controlled by temperature. It is possible that the warm water temperature positively affected the reproduction of the *O. similis* TWW population before the intrusion of the OCCW in Funka Bay in early winter. Therefore it is considered that the food availability in Funka Bay is unchanged geographically independent the difference of the density of female *O. similis* of the two water masses and the intrusion period of the OCCW.

During the last decade, first-feeding larval pollock have occurred from January to February in Funka Bay and its mouth region and interannual change in the density of pollock larvae has been observed (Nakatani et al., 2003a). As shown in Table 4, the density of the larvae from January to March 2002 was considerably low. In 1993, a low density of pollock larvae was also observed (Nakatani et al., 2003a). In 1993 and 2002, the OCCW entered the bay earlier than in other years (Fig. 3, Samejima, unpublished data). As stated before, pollock eggs are spawned from the bay mouth to the eastern area outside the bay. Therefore, we supposed that the early intrusion of the OCCW dispersed the pollock eggs, and the small numbers of the eggs were transported into the bay. In winter 2003, the density of pollock larvae was not so high in spite of the delayed intrusion of the OCCW. This might reflect the low density of adults pollock inferred by the small amount of the commercial catch of the bottom gill net operated near the spawning area (38,249 metric tons in 2001; 28,290 metric tons in 2002; 13,555 metric tons in 2003). To understand the emergence of larval pollock, it needs further investigation concerning to the spawning period, density of spawners, and hydrographic conditions.

Nakatani et al. (2003a) suggested that the survival of first-feeding pollock larvae is affected by their early transportation to the center of the bay, where the TWW occupied and warm water temperature prevailed. Therefore it can be considered that the percentage of the pollock eggs transported in the bay before the intrusion of the OCCW affects the feeding success for the first-feeding larvae. It would be supposed that the feeding activities of the larvae in 1993 and 2002 (the years of the early intrusions of the OCCW) were low.

Acknowledgement

The authors are grateful to Dr. Jeffery M. Napp, NOAA/Alaska Fisheries Science Center, Associate Professor John Bower and Professor Tsutomu Ikeda, Graduate School of Fisheries Sciences, Hokkaido University for critically reading the manuscript and their many valuable comments. Our thanks go to Professor Toyomi Takahashi and Associate Professor Tetsuya Takatsu, Graduate School of Fisheries Sciences, Hokkaido University for their useful discussions. The authors would like to thank the students of our laboratory for field samplings. Thanks are also due to the captains and crew members of the R/V *Ushio Maru* and T/S *Oshoro Maru*, Faculty of Fisheries, Hokkaido University for their kind assistance.

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