

Influence of Physical Parameters on Zooplankton Variability during Early Ocean Life of Juvenile Chum Salmon in the Coastal Waters of Eastern Hokkaido, Okhotsk Sea

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Abstract: Zooplankton variability during the early life of juvenile chum salmon and its relationship to physical environmental variability were studied from 2002 to 2004 in the Okhotsk Sea along the coast of eastern Hokkaido. During the study, the zooplankton taxa, Hydrozoa, Cladocera, Copepoda, Euphausiacea, Echinodermata and Appendiculata were commonly found. Cladocera, Copepoda, and Appendiculata were numerically dominant. At the boundary of the Soya Warm Current, the predominant zooplankton taxa shifted from Copepoda to Cladocera-Appendiculata. The predominant species of Copepoda, Cladocera and Appendiculata taxa were divided into two groups, based on their abundance and preferred water temperature and salinity. Group I was made up of cold-water species that prefer temperatures < 12°C and salinities < 33.6 psu. Group II was made up of warm-water species that prefer temperatures > 12°C and salinities > 33.6 psu. Several species in Group I are important components in the diets of juvenile chum salmon. In Group I the cold-water copepod, *Pseudocalanus newmani*, was the most numerous species in Abashiri Bay from 2002 to 2004. Pelagic cold-water copepods (*Neocalanus* spp. other than *Neocalanus cristatus*) and neritic cold-water copepods (*Eurytemora herdmani* and *Tortanus discaudatus*) were more abundant in 2004 than in 2002 or 2003. We theorize that the abundance of pelagic copepods may be related to the timing of the retreat of sea ice, and that the abundance of neritic copepods may be related to the displacement of less saline water under the influence of terrestrial inputs. The Soya Warm Current, sea ice, and less saline water are thought to be key factors affecting zooplankton variability and, by extension, influencing the life modes of juvenile chum salmon in the Okhotsk Sea.

Keywords: Soya Warm Current, sea ice, low salinity, pelagic copepod, neritic copepod, spring blooms, zooplankton abundance

INTRODUCTION

Because the period of early ocean residence is thought to be a critical stage in the life history of anadromous salmonids, ocean conditions during this period may be important in determining their population size (Healey 1982; Bax 1983; Willette et al. 2001; Fukuwaka and Suzuki 2002). Zooplankton variability might be one of the most important factors affecting the survival of juvenile chum salmon (*Oncorhynchus keta*), because they habitually prey on zooplankton (Okada and Taniguchi 1971; Pearcy 1992; Mayama and Ishida 2003). According to the ‘match / mismatch hypothesis’ of Cushing (1990), fish survival depends on whether the

feeding stage of fish development synchronizes with the seasonal cycle of food production, or not. Seasonal changes in zooplankton abundance during the early life of chum salmon have been studied extensively (LeBrasseur 1969; Walters et al. 1978; Sibert 1979; Kaeriyama 1986; Asami and Hirano 1993; Seki 2005). The coasts bordering the Okhotsk Sea are covered with sea ice until early spring when the ice melts, and less saline water is mixed with meltwater and water from terrestrial sources (Ohtsuki 1982). By late spring, the Soya Warm Current (SWC) begins to prevail (Takizawa 1982; Aota 1984; Irie 1990). As a result, juvenile chum salmon in these coastal areas experience extreme changes in their ocean habitat. A previous study (Irie 1990) reported that juvenile

chum salmon that were affected by changes in coastal water parameters, rarely venture offshore into the Okhotsk surface water. Further, the study suggested that juvenile chum salmon disappear from coastal waters in July, when the SWC begins to prevail and zooplankton biomass simultaneously begins to decline. It is important to relate the succession of zooplankton communities by species to environmental changes along the Okhotsk Sea coasts, in order to better understand the early life history of chum salmon. Thus, we studied the relationships between zooplankton variability, physical conditions, and juvenile chum salmon populations in Abashiri Bay, near eastern Hokkaido, from 2002 to 2004.

MATERIALS AND METHODS

Study sites were located along four transects (A, B, C, D), each with stations 1 km, 4 km, and 7 km off Hokkaido's eastern coast in Abashiri Bay (Fig. 1). There were 12 stations in all with water depths ranging from 10–40 m. Surveys were conducted once every ten days from April to July, 2002–2004. Water temperature and salinity were measured with a Memory STD (Salinity-Temperature-Depth, Alec Electronics Co., Ltd.). Surface water temperatures were measured with a thermometer from surface bucket samples.

At the same time, water for analysis of chlorophyll-*a* concentration was collected from the surface at each station. One L of water was brought back to the laboratory in a cooled container. From this sample, 300 mL was filtered through a 47-mm Whatmann GF/F filter. The filters were frozen and stored for about one month before the chlorophyll-*a* was

measured. Following the procedure established by Parsons et al. (1984), we measured chlorophyll-*a* concentrations with a Turner Designs fluorometer (Model AU-10).

Zooplankton samples were collected from near the bottom to the surface with a Norpac net (45-cm mouth and 0.33-mm mesh size). The net was towed vertically at about 0.5 m/s. Because a flow meter was not used with the plankton net, the volume filtered was calculated from tow depth. Water filtration efficiency was assumed to be 100%. After collection, zooplankton samples were immediately fixed in 5% buffered formalin. At the laboratory, a plankton splitter was used to divide samples into subsamples (Motoda 1959), depending on abundances, and a dissecting microscope was used to count the number of zooplankton (inds./m³) in each taxon group and species.

RESULTS

The Physical Environment and Chlorophyll-*a* Concentrations

Average sea surface temperature (SST) at each coastal station fluctuated from 4.1 to 14.9°C in 2002, from 2.2 to 14.5°C in 2003 and from 5.7 to 16.4°C in 2004. SSTs were uniform at the 1-, 4-, and 7-km locations (Fig. 2a). SSTs in 2002 and 2004 showed similar fluctuations, except for the sudden decrease in late June 2002. In late April of 2003, we observed the lowest SSTs (2.6°C at one km, 2.4°C at four km, and 2.2°C at 7 km offshore). Although the SSTs rose to 5–6°C by early May, lower SSTs continued until late May at

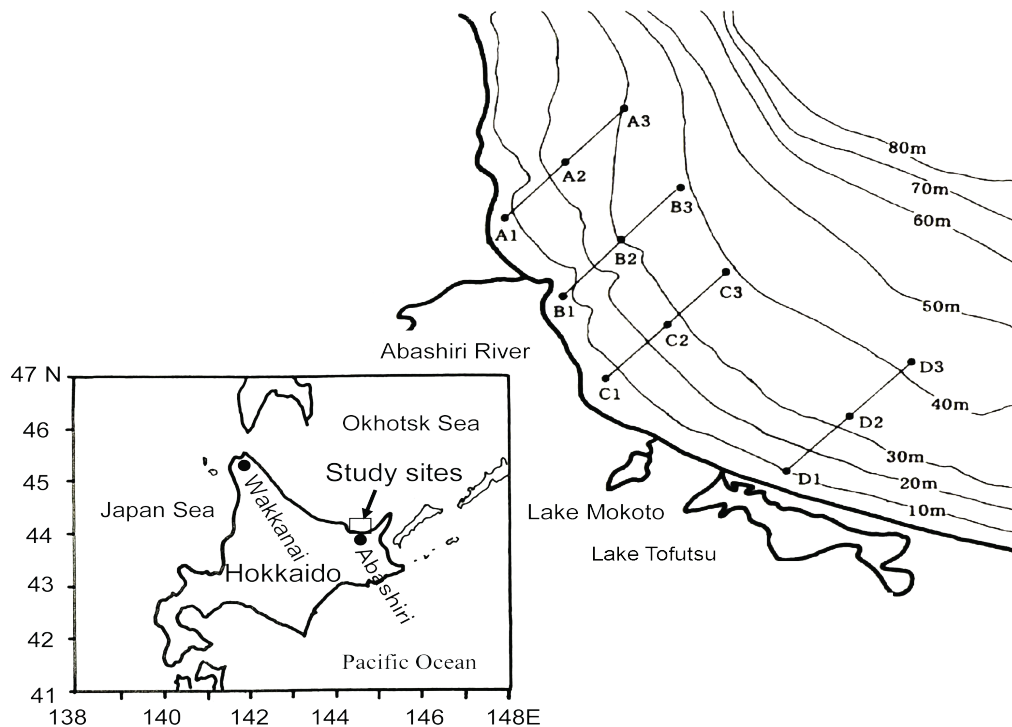


Fig. 1. Maps showing the study sites 1 km, 4 km and 7 km off the Abashiri coast in the Okhotsk Sea.

all locations in 2003.

Average sea surface salinity (SSS) varied from 32.0 to 33.6 psu in 2002, 31.1 to 33.7 psu in 2003, and 31.6 to 33.5 psu in 2004 (Fig. 2b). SSSs increased by early June at all locations in 2002. However, they decreased in mid-June. SSSs in 2003 fluctuated considerably compared to the other two years, especially at the one-km location. Although SSS in 2003 were very low from late April to late May, they began to increase in early June. In 2004, SSSs at 1 km and 4 km offshore showed similar fluctuations. Decreases in SSSs were observed in mid-May. In order to examine the SWC's impact on Abashiri Bay, we measured the average salinity at depths of 5 m, 15 m and 20 m offshore (Fig. 2c). The SWC appeared in early June and July of 2002, as indicated by a salinity value of 33.6 psu (Aota 1984) at 7 km offshore. Although the same salinity was not observed at 1 and 4 km offshore, these sites had highly saline water from mid-May to June (33.3–33.4 psu) at 1 km, and from early June (33.5 psu) at 4 km offshore. For the first time, the SWC was found from mid-June at 7 km offshore in 2003, and appeared from late June at four km offshore. Finally, it was detected in mid-July at 1 km offshore. The SWC appeared intermittently in 2004.

The first appearance of the SWC was observed in early May at seven km offshore. Thereafter in 2004, the SWC appeared from late June at all locations, except for 1 km offshore in mid-July.

Average surface chlorophyll (chl-*a*) concentrations from late April to mid-May fluctuated widely throughout the study (Fig. 2d). Although the highest chl-*a* (2.3 g/L) was found in late April 2002 at 1 km offshore, a clear peak was not detected in our investigations. In contrast with 2002, clear peaks were found in 2003 and 2004. Peaks in chl-*a* were observed in late April 2003 at both 4 and 7 km offshore. Chl-*a* peaked from late April to early May, reaching the highest levels at all locations in 2004.

Zooplankton Abundance and Taxonomic Composition

The average abundance of zooplankton at 1 km offshore were generally larger than at 4 or 7 km offshore (Fig. 3a). At 1 km offshore, zooplankton abundance peaked in late April (5.1×10^3 inds./m³) and mid-May (6.3×10^3 inds./m³) in 2002, in early May (4.8×10^3 inds./m³) and mid-June (5.8×10^3 inds./m³) in 2003, and in early May (11.5×10^3 inds./m³) and late

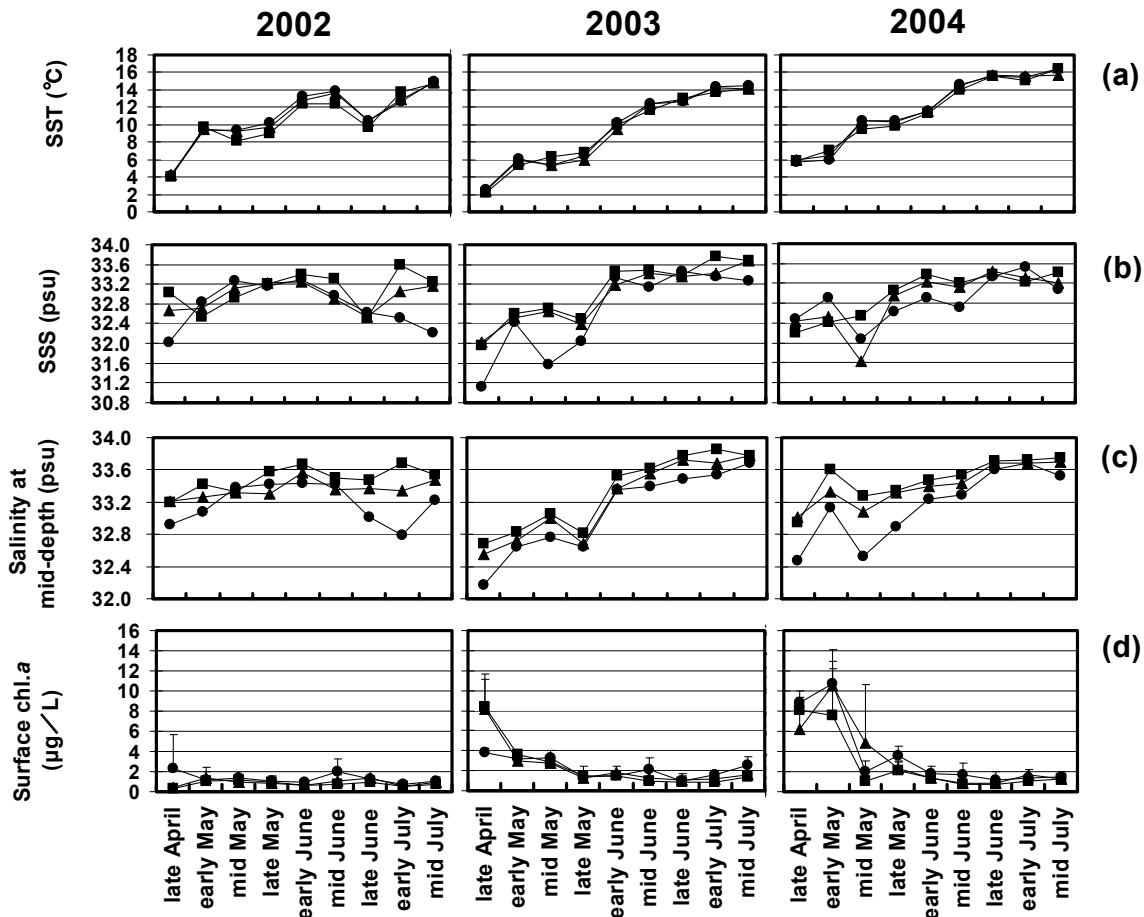


Fig. 2. Seasonal changes in averages of (a) sea surface temperature (SST), (b) sea surface salinity (SSS), (c) mid-depth salinity, (d) surface chlorophyll-*a* concentrations at 1 km (circles), 4 km (triangles), and 7 km (squares) off the Abashiri coast from 2002 to 2004. Bars in figure (d) indicate positive standard deviation.

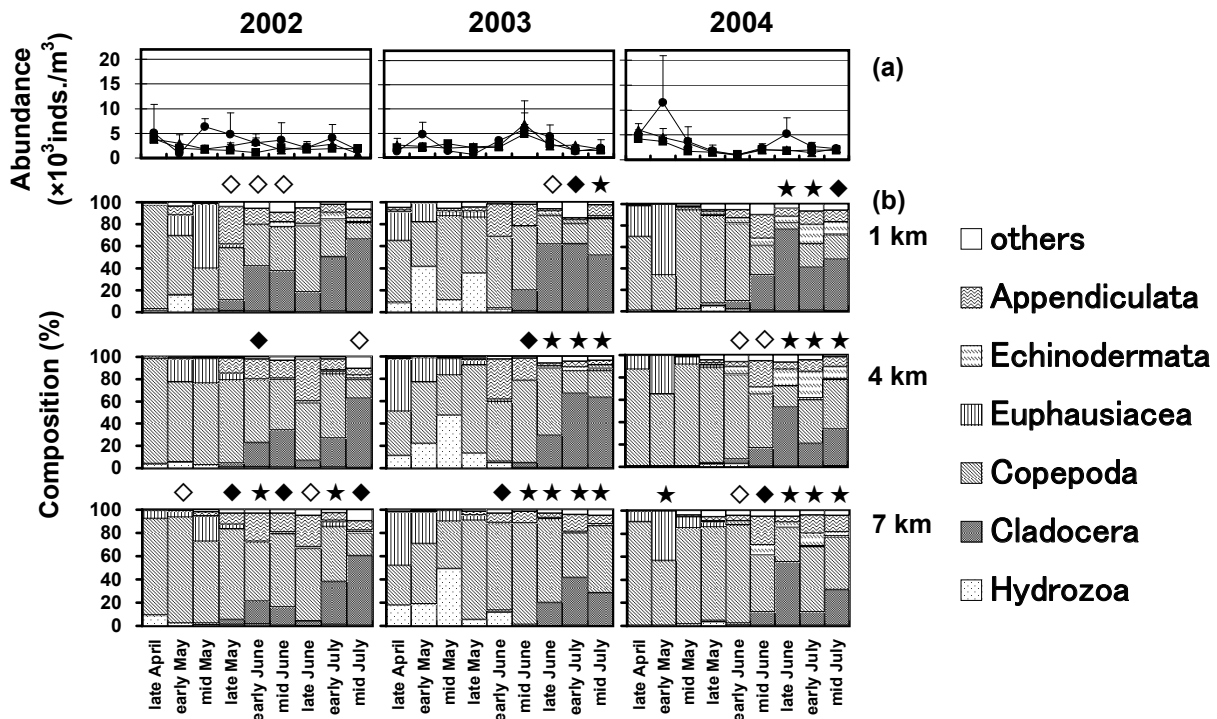


Fig. 3. Seasonal changes in averages of (a) total zooplankton abundance, (b) numerical composition of dominant zooplankton taxa at 1 km, 4 km and 7 km off the Abashiri coast from 2002 to 2004. In figure (a), bars indicate positive standard deviation. In figure (b), stars indicate observed SWC salinity ≥ 33.6 psu; filled diamonds indicate 33.5 psu; open diamonds indicate 33.4 psu at mid-depth at each location off the coast.

June (5.2×10^3 inds./m³) in 2004. The later-occurring maximums in 2002 and 2003 coincided with periods when water temperatures exceeded about 10°C. With the exception of mid-June in 2003 and late June in 2004, total zooplankton abundances decreased gradually until mid-July of each year.

Six of the most numerous zooplankton taxa were the Hydrozoa, Cladocera, Copepoda, Euphausiacea, Echinodermata and Appendiculata (Fig. 3b). In these taxa, Cladocera, Copepoda and Appendiculata were always predominant. Hydrozoa predominated from late April to late May in 2003 at 1 and 4 km offshore. Hydrozoa made up 41% of the total zooplankton abundance in early May 2003 and thus contributed significantly to the earliest maximum in zooplankton abundance. Euphausiacea (mainly eggs) was the dominant taxon from early to mid-May in 2002, and from late April to mid-May in 2003 and 2004. Euphausiacea made up 58% of the total zooplankton abundance in mid-May 2002 at 1 km offshore, when the second maximum in zooplankton abundance occurred. In early May 2004, Euphausiacea made up 34–66% of the total zooplankton abundance at each location and contributed to the earliest maximum in zooplankton abundance. Echinodermata became sizeable enough to be counted after mid-June 2004 at all locations. Copepoda was one of the most important taxa throughout this investigation and were numerous until the appearance of the SWC (≥ 33.6 psu), especially in 2003 and 2004. Although the SWC appeared intermittently or not at all in 2002, Copepoda numbers usually decreased under high salinity conditions. How-

Table 1. List of dominant species including those comprising > 2% of total abundance of zooplankton. Open circles: warm-water species; solid circles: cold-water species; squares: eurythermic species; triangles: temperature preference not clear.

Taxa	Species
Hydrozoa	□ <i>Rathkea octopunctata</i>
	△ <i>Obelia</i> sp.
Gastropoda	△ Unidentified larva
Cladocera	○ <i>Podon leuckarti</i>
	○ <i>Evadne nordmanni</i>
Copepoda	● <i>Neocalanus</i> spp. other than <i>N. cristatus</i>
	○ <i>Mesocalanus tenuicornis</i>
	○ <i>Paracalanus parvus</i>
	● <i>Pseudocalanus newmani</i>
	● <i>Eurytemora herdmanni</i>
	● <i>Metridia pacifica</i>
	● <i>Centropages abdominalis</i>
	● <i>Acartia hudsonica</i>
	● <i>Acartia longiremis</i>
	● <i>Tortanus discaudatus</i>
● <i>Oithona atlantica</i>	
Euphausiacea	● <i>Thysanoessa inermis</i> egg
	<i>T. inermis</i> nauplius
	<i>T. inermis</i> calyptopis
	<i>T. inermis</i> furcilia
Decapoda	△ <i>Pinnixa</i> sp. Zoea
Echinodermata	△ <i>Echinopluteus</i> larva
	△ <i>Ophiopluteus</i> larva
Appendiculata	○ <i>Oikopleura longicauda</i>
	□ <i>Oikopleura dioica</i>
	● <i>Fritillaria borealis</i> f. <i>typica</i>
Fish	○ <i>Enguraulis japonicus</i> egg

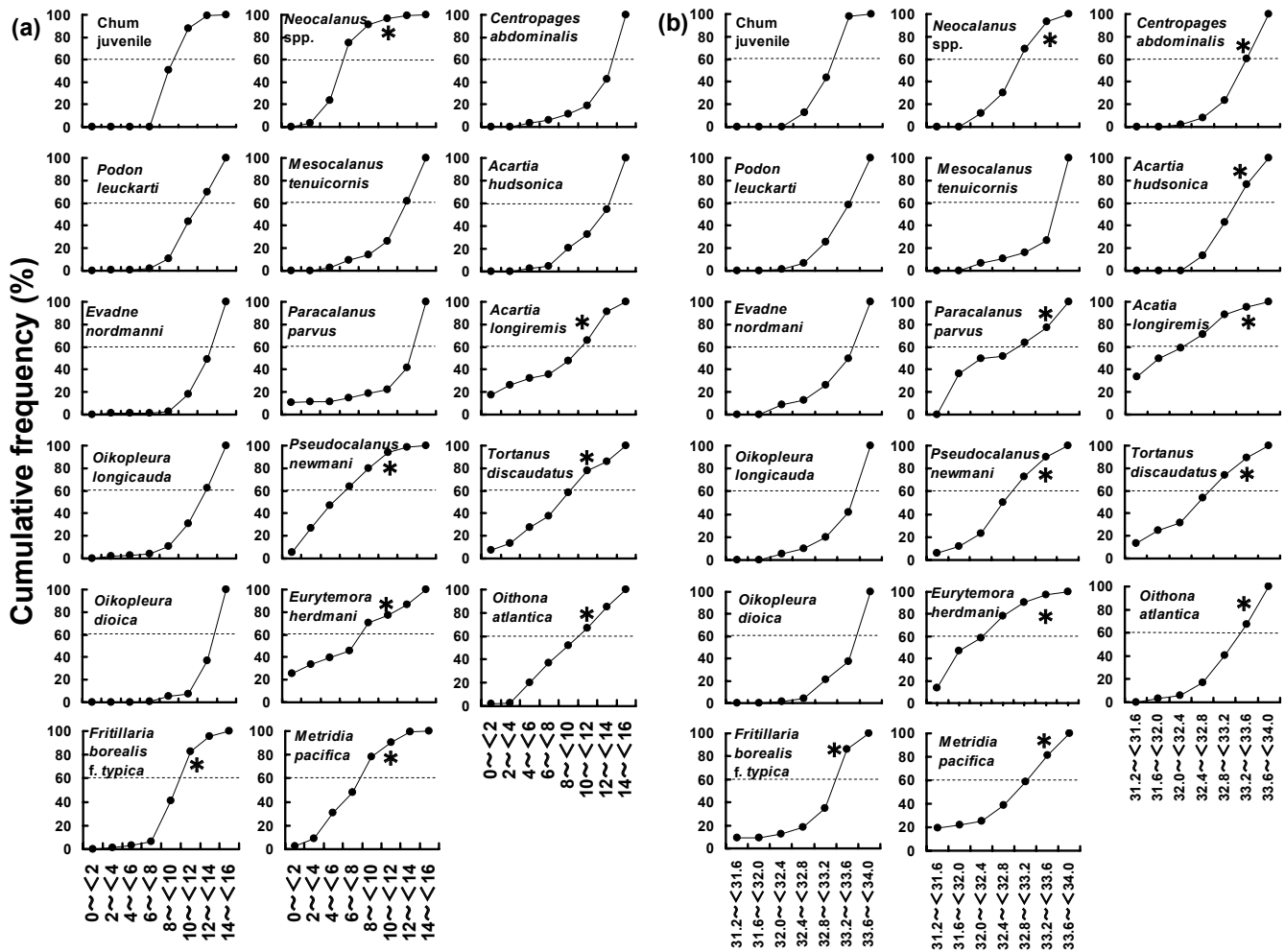


Fig. 4. Cumulative frequency distributions plotted against (a) water temperature and (b) salinity. All data from 2002 to 2004 are included. Water temperature and salinity throughout the water columns are averaged at 5-m intervals. Data for chum juveniles are taken from Nagata et al. (2007). Asterisks indicate species whose cumulative frequency reached 60% below 12°C, and below 33.6 psu.

ever, as Copepoda declined, Cladocera and Appendiculata became more numerous, predominating from early June in 2002, early to mid-June in 2003, and mid- to late June in 2004. At 1 km offshore, Cladocera and Appendiculata made up 38% of the zooplankton in mid-June in 2003, and 84% of the zooplankton in late June in 2004. During our investigations, we observed that the composition of the zooplankton community in Abashiri Bay shifted from Hydrozoa, Euphausiacea and Copepoda to Cladocera and Appendiculata when the SWC appeared.

Table 1 indicates which species made up more than 2% of the total zooplankton at each coastal location from 2002 to 2004. Nine taxa and 24 species were defined as numerically dominant. Dominant species were mostly cold-water species. Cladocera, Copepoda and Appendiculata were common throughout the investigation (Fig. 3b).

Species Appearances Associated with Water Properties and Their Temporal Changes

In order to examine the relationships between the abundance of 16 species belonging to the three higher-order taxa Cladocera, Copepoda and Appendiculata, chum salmon juveniles, water temperature and salinity, the cumulative frequency distributions for each species were plotted against water temperature and salinity (Fig. 4). The cumulative frequency of chum salmon juveniles reached over 80% at a water temperature < 12°C and salinity < 33.6 psu. We chose the important species during the residence of chum salmon juveniles in the bay, whether the cumulative frequencies reached 60% or not at the boundary of a water temperature of 12°C and a salinity of 33.6 psu. As a result, for eight species (*Fritillaria borealis f. typica*, *Neocalanus* spp. other than *N. cristatus*, *Pseudocalanus newmani*, *Eurytemora herdmani*, *Metridia pacifica*, *Acartia longiremis*, *Tortanus discaudatus* and *Oithona atlantica*), the cumulative frequencies reached

60% below 12°C. By contrast, for eleven species (*F. borealis* f. *typica*, *Neocalanus* spp. (other than *N. cristatus*), *Paracalanus parvus*, *Pseudocalanus newmani*, *E. herdmani*, *M. pacifica*, *Centropages abdominalis*, *A. hudsonica*, *A. longiremis*, *T. discaudatus* and *O. atlantica*), the cumulative frequencies reached 60% below 33.6 psu. From these results,

the dominant species were divided into two groups. Group I includes species that showed a pattern similar to that of chum salmon juveniles and prefers water temperatures < 12°C and salinities < 33.6 psu. Group II includes species that prefer water temperatures > 12°C and salinities > 33.6 psu. Group I includes all cold-water species, and Group II includes al-

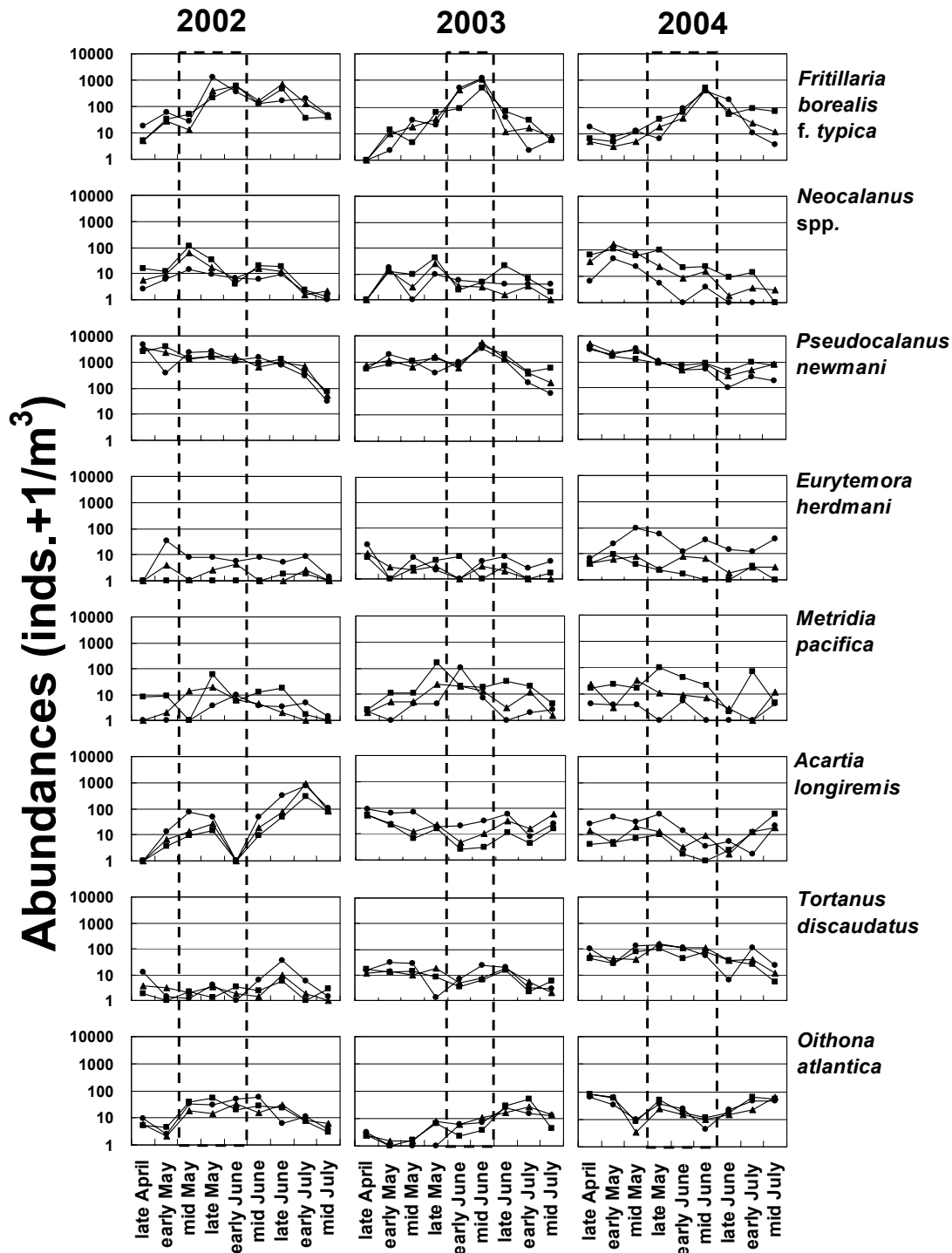


Fig. 5. Seasonal changes of abundances for species belonging to Group I from 2002 to 2004. Abundances are averaged at 1 km (circles), 4 km (triangles) and 7 km (squares) offshore. Dashed rectangles show the durations of chum salmon juvenile high CPUEs (Nagata et al. 2007).

most all warm-water species except for *C. abdominalis* and *A. hudsonica*.

Figures 5 and 6 indicate the seasonal average abundance of dominant species belonging to Groups I and II from 2002 to 2004, respectively. The fluctuations of *F. borealis* f. *typica* in 2002–2004 did not differ among locations (Fig.

5). This species increased from late April and peaked in late May to early June 2002, and in mid-June in 2003 and 2004. High abundance of *Neocalanus* spp. (other than *N. cristatus*) was observed in May and decreased rapidly thereafter in all years. *Neocalanus* spp. was more abundant at 4 and 7 km offshore. The maximum abundance was observed at 4

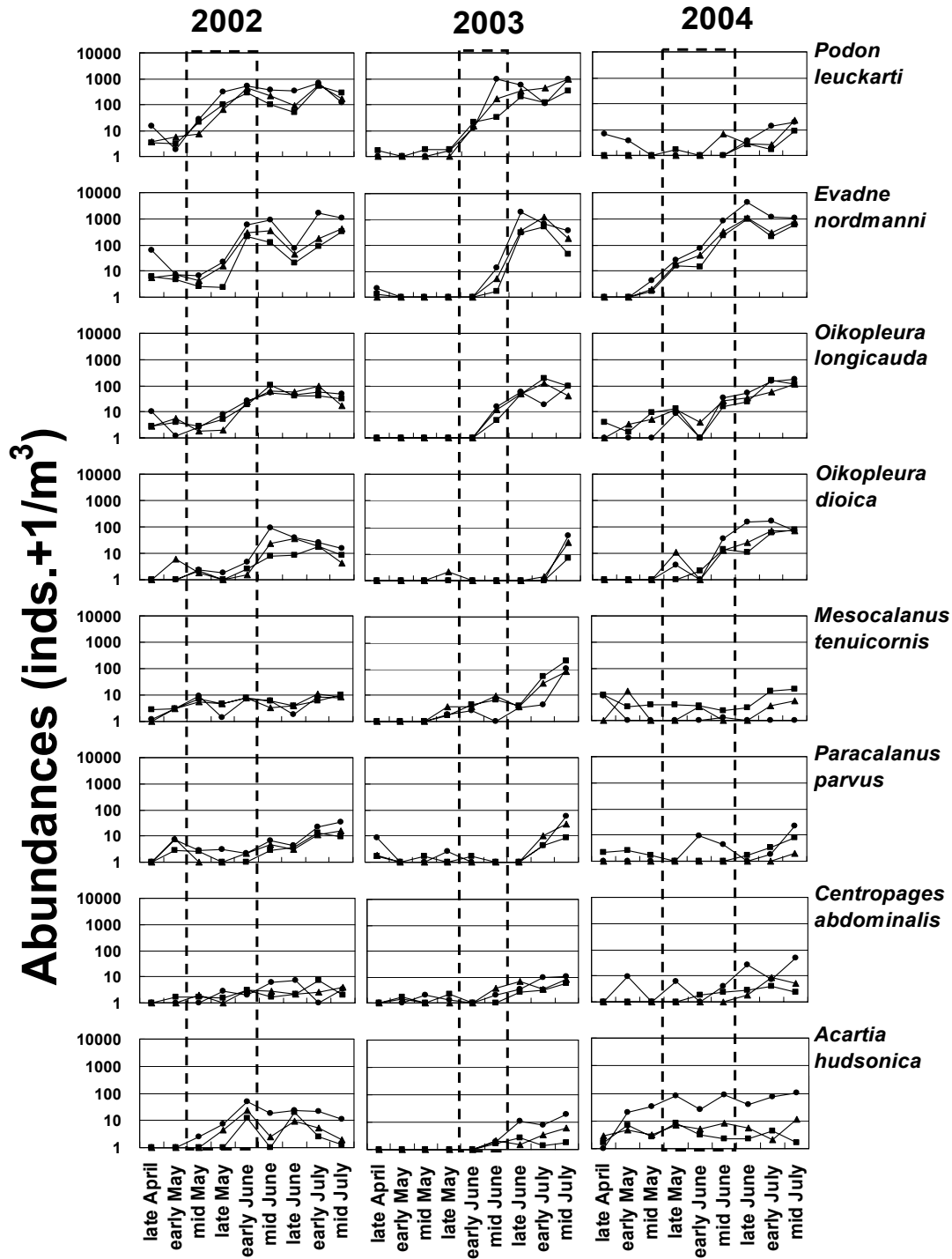


Fig. 6. Seasonal changes in abundance for species belonging to Group II from 2002 to 2004. Abundances are averaged at 1 km (circles), 4 km (triangles) and 7 km (squares) offshore. Dashed rectangles show the duration of chum salmon juvenile high CPUEs (Nagata et al. 2007).

km offshore in early May 2004. The abundance of *Pseudocalanus newmani* did not differ among the three years at each location, and were the most numerous during our observations. High abundances ($>10^3$ inds./m³) of *P. newmani* were observed from late April to late June in 2002 and 2003, from late April to late May in 2004. *Eurytemora herdmani* had < 10 inds./m³ at each location in 2002 and 2003. However, a high abundance of this species was observed at 1 km offshore in 2004. *Metridia pacifica* was more abundant at 7 km offshore and peaked in late May in each of the three years. *Acartia longiremis* showed clear seasonal changes in 2002. This copepod increased from late April and peaked in mid-May, then increased from mid-June reaching a second peak in early July. *Tortanus discaudatus* was more abundant in 2004, especially at 1 km offshore and maintained an abundance of about 10^2 inds./m³ from mid-May to early June. *Oithona atlantica* had abundances of $< 10^2$ ind./m³ at each location in the three years and was distributed widely in the bay. Higher abundances were observed from mid-May to June 2002, early July 2003, and late April and July 2004. Through our investigations, chum salmon juveniles in 2004 could encounter high abundances of *Neocalanus* spp., *E. herdmani*, and *T. discaudatus*.

Abundances of the eight species belonging to Group II almost always increased in June or July (Fig. 6). Abundances of *Podon leuckarti* and *Evadne nordmanni* were higher at 1 km offshore and increased in June of all years, with the exception of *P. leuckarti* in 2004. Abundance of *P. leuckarti* in 2004 was very low (< 10 inds./m³). *Oikopleura longicauda* and *O. dioica* increased in June or July. Higher abundance of *Mesocalanus tenuicornis* were observed at 7 km offshore. In 2003, *M. tenuicornis* increased rapidly in July. *Paracalanus parvus* and *C. abdominalis* had < 10 inds./m³, and increased in July at 1 km offshore. The abundance of *A. hudsonica* was $< 10^2$ inds./m³ throughout 2002–2004. Higher abundances from late May to mid-July were found at 1 km offshore in 2004. Throughout our investigation, *Podon leuckarti* in 2002, and *E. nordmanni* and *A. hudsonica* in 2004 were more abundant than other species during the residence of juvenile chum salmon.

DISCUSSION

Coastal areas of Abashiri Bay in the Okhotsk Sea are seasonally affected by the SWC and sea ice (Takizawa 1982; Aota 1984). Further, terrestrial water flows into the bay resulting in a decrease in salinity (Ohtsuki 1982). The physical parameters studied in our surveys fluctuated significantly over time. The water temperature and salinity in the bay changed most drastically from late April to late May in 2003, decreasing from their usual levels. Such low water temperatures and salinity seem to be related to the timing of the retreat of sea ice. In 2003, sea ice remained in the bay for a longer time than usual (Japan Meteorological Agency), retreating on 28 April, the latest date among the three survey

years.

A few other physical events were observed in this study. For example, the salinity at each mid-level depth at each transect dropped suddenly from mid- to late June of 2002. Although the mechanism is not clear, such a decrease in salinity is thought to be caused by the influx of offshore surface water, because a decrease in SST was observed simultaneously with the drop in salinity. This phenomenon may have also weakened the influence of the SWC in 2002. A decline in salinity was also observed in mid-May in 2004. At that time, corresponding decreases in water temperature were not measured at any of the observation stations. This less saline water is thought to be caused by the input of terrestrial waters (Ohtsuki 1982). Finally, the SWC appeared suddenly in early May 2004 at 7 km offshore. It is known that the movement of the SWC is dependent on the differences in sea level between Wakkanai (the northernmost part of Hokkaido) and Abashiri (the eastern part of Hokkaido) (Aota 1984). The difference in sea level between Wakkanai and Abashiri increased suddenly in early May 2004 (Japan Oceanographic Data Center), so the movements of the SWC and accompanying phenomena are thought to be caused by the variation in sea level.

Spring phytoplankton blooms were not detected during the 2002 investigations. On the other hand, spring blooms were observed in late April 2003, farther offshore. Shimizu et al. (2000) reported that, in the northern Nemuro Strait of Hokkaido, spring phytoplankton blooms appeared soon after the sea ice had retreated from seasonally frozen coastal areas. Because we observed spring phytoplankton blooms as the sea ice retreated, Shimizu et al. (2000) may have been correct in his hypothesis. On the other hand, we observed spring blooms from late April to early May 2004, but the sea ice retreated on 24 March (Japan Meteorological Agency). Although the blooms' cause was not established in 2004, we observed less saline water (but not low temperatures such as in 2003) developed in the bay. Nutrient-rich water was also observed in late April (Sawada et al. 2006). The less saline water affected by terrestrial inputs might have prevailed in 2004, resulting in rich nutrients and spring blooms.

The SWC dynamics were thought to be an important factor, because we observed that the community succession patterns of zooplankton were closely related to the SWC's movements. Dominant species were divided into two groups at the boundaries of water temperature (12°C) and salinity (33.6 psu (the level in the SWC)). Species belonging to Group I were composed of cold-water species and the timing of their appearance was similar to that of juvenile chum salmon. Several species were also identified in juvenile chum salmon diets (Nagata et al. 2007). Asami et al. (2005) suggested the high preferences for *Neocalanus* spp., *Metridia pacifica* and *T. discaudatus*. Pelagic calanoid copepods such as *Neocalanus* spp. are known to be an important food source for juvenile chum salmon as they move to open neritic waters (Simenstad and Salo 1980). Furthermore, *Neo-*

calanus spp. are large in size, and it is known that juvenile chum salmon begin to prey on larger zooplankton, when their fork length reaches 50–60 mm (Okada and Taniguchi 1971; Suzuki et al. 1994). Pelagic cold-water calanoid copepods, *Neocalanus* spp. were predominant in 2004. According to previous studies of *Neocalanus* spp. life cycles in the western, sub-Arctic Pacific Ocean (Kobari and Ikeda 2000), *Neocalanus* spp. complete ontogenetic migrations that coincide with phytoplankton production cycles in the surface layer, and grow more rapidly from the early to the late copepodite stages, synchronizing with spring phytoplankton blooms. Thus, occurrence of spring phytoplankton blooms in pelagic areas of the Okhotsk Sea may be key factor in the growth of *Neocalanus* spp. Shimizu (2005) postulated that the magnitude and timing of spring blooms were determined by the movement of sea ice in the Okhotsk Sea. When sea ice retreats earlier, spring blooms may appear earlier, and the zooplankton biomass may increase. According to the data of the Japan Meteorological Agency, the sea ice retreated earlier in 2002 and 2004 (24 March) than in 2003 (28 April). Although the sea ice retreated at nearly the same time in both 2002 and 2004, the ice remained for a shorter period of time in 2004 (54 days) than in 2002 (89 days). If Shimizu's hypothesis is applied to our study, we may theorize that high abundances of *Neocalanus* spp. in 2004 resulted from the early sea ice retreat. However, it is not clear how the sea ice influences zooplankton abundance when it remains in place. It is not also known how pelagic copepods move into coastal areas. However, there may be some hints. *Neocalanus* spp. increased in early May 2004, when the highly saline water (SWC) appeared. In contrast with *Neocalanus* spp., it is probable that *A. longiremis* was transported to the bay in offshore surface water, because *A. longiremis* became more numerous when water temperatures and salinity in the bay were low in June 2002. *Pseudocalanus newmani* was the most abundant species during our investigations. In southwestern Hokkaido, *P. newmani* appeared throughout the year in water shallower than 200 m and peaked in abundance after the spring blooms emerged: abundance decreased when water temperatures reached 15°C (Yamaguchi and Shiga 1997). The spring distributions of *P. newmani* in Abashiri Bay might be similar to those seen in the Pacific Ocean, because *P. newmani* decreased when the SST reached 15°C in mid-July. *P. newmani* was abundant in more distant areas in spring (Asami, unpublished data). It is suggested that *P. newmani* was distributed widely from coastal to offshore areas. In 2004, it was also discovered that common neritic species such as *E. herdmani* and *T. discaudatus* were particularly numerous from mid- to late May at one km offshore. *Eurytemora herdmani* is distributed in freshened sea water, and *T. discaudatus* can also withstand freshened water (Brodskiy 1950). Higher abundance in 2004 may be related to the displacement of less saline water by terrestrial water inputs in late April and May. Resting eggs of zooplankton in bottom sediments were found along with *T. discaudatus* in coastal northern Califor-

nia (Marcus 1990). These eggs may play a potential role in the growth of local plankton populations. The changes in abundance of these species are controlled by local growth and reproduction, and high abundance occurs after a period of favorable growing conditions, which are determined largely by temperature and salinity. Within Group II *Podon leuckarti*, *Evadne nordmanni* and *O. longicauda* were also found in juvenile chum salmon diets (Nagata et al. 2007). Because the residence time of chum salmon juveniles overlapped the period of increased abundance of these species, juvenile chum salmon could utilize these species. *Acartia hudsonica* was more abundant in June and July 2004, although this species has not been described in diets of chum juveniles (Nagata et al. 2007). The occurrence of *A. hudsonica* in estuarine environments and the contribution of dormant eggs to plankton populations have been suggested in Maizuru Bay of Honshu, Japan (Ueda 1987). It may be that displacement of less saline water in 2004 might be related to the appearance of this species along with *Eurytemora herdmani* and *T. discaudatus*, creating favorable conditions for growth.

Throughout our investigations, the features of several copepods' appearance in 2004 were different from 2002 and 2003. Only horizontal abundances of zooplankton are described in the present study. Because chum salmon juveniles are distributed in the surface layer (Moulton 1997), the zooplankton vertical distributions must be also studied in order to explain why and how the species are utilized (e.g. Seki 2005).

The movement and composition of the SWC, sea ice and less saline water affected by terrestrial inputs may have been factors influencing zooplankton variability during the early life of juvenile chum salmon in the Okhotsk Sea. The growth of juvenile chum salmon population was greatest in 2004 (Nagata et al. 2007). In the future, biological analyses of returning adult salmon may prove a link between zooplankton variability and growth or mortality of chum salmon in their early life.

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