Spatial and seasonal distributions of copepods from spring to summer in the Okhotsk Sea off eastern Hokkaido, Japan

Hiroki Asami[1], Hiroshi Shimada[2], Mayumi Sawada[2], Yasuyuki Miyakoshi[3], Daise Ando[3], Makoto Fujiwara[3] and Mitsuhiro Nagata[3]

[1] Hokkaido Wakkanai Fisheries Experiment Station,[1] Wakkanai, Hokkaido, Japan
E-mail: asamih@fishexp.pref.hokkaido.jp
[2] Hokkaido Central Fisheries Experiment Station, Yoichi, Hokkaido Japan
[3] Hokkaido Fish Hatchery, Kitakashiwagi-3, Eniwa, Hokkaido Japan

Abstract

Spatial and seasonal distributions of copepods were investigated in the Okhotsk Sea off eastern Hokkaido, in relation to the hydrography from spring to summer in 2002. Several cold water species such as *Neocalanus* spp. other than *Neocalanus cristatus*, *Pseudocalanus minutus*, *Pseudocalanus newmani*, *Metridia pacifica*, *Metridia okhotensis*, *Acartia longiremis*, and *Oithona similis* were predominant. Three groups of coastal, pelagic, and mixtures of coastal and pelagic copepod assemblages were identified during the investigations. These assemblages might be affected by the Soya Warm Current (SWC) and the extension of the front of Cold Intermediate Water (CIW).

Introduction

Copepods are the most numerous taxonomic group in the zooplankton community and are important as links between primary production and many species of fishes in the ecosystems (Mauchline, 1998). The Okhotsk Sea along the coast of Hokkaido supports many fishery resources such as salmon, herring, walleye pollock, arabesque greenling, *etc*. Copepods are one of the most important prey for these fishes (Motoda and Sato, 1949; Kamba, 1977; Blaxter and Hunter, 1982; Pearcy, 1992). We studied the spatial and temporal variability of zooplankton, including copepods, in near the coasts of the Okhotsk Sea off eastern Hokkaido, as part of an ecological study of juvenile chum salmon (Asami *et al.*, 2007), and suggested that the Soya Warm Current (SWC) along the coast of the Okhotsk Sea of Hokkaido might be one of the key factors affecting zooplankton variability. Irie (1990) also studied the seasonal biomass of zooplankton in waters further off-shore of the Okhotsk Sea of eastern Hokkaido from spring to summer. However, there is little information on the zooplankton community at the species level. This study was conducted in order to describe the copepod assemblages and to understand the factors affecting copepod variability from spring to summer in the Okhotsk Sea off eastern Hokkaido.

Materials and Methods

Study sites were located along O3 line (44°02.1′N ~45°08.1′N, 144°19.8′E), established as a monitoring line by the Hokkaido Fisheries Experiment Station (Fig. 1). Six stations were on this line. Since this line transverses along the Kitami-Yamato Rise, the depth between Stn. O34 and St. O36 varied greatly. Investigations were conducted in mid-April (April 16 and 17), early June (June 3 and 4) and late July (July 22 and 24) in 2002. Water temperature and salinity were measured by using a CTD. Surface water temperature was measured with a thermometer from a surface bucket sample. Surface salinity was also sampled by bucket and determined by salinometer in the laboratory.

Zooplankton samples were collected with a Norpac net (45-cm mouth and 0.33 mm mesh size) equipped with flowmeter from 150 m at Stn. O33, O34, O35 and O36 or near bottom at Stn. O31, and O32 from the surface. The net was towed vertically at a speed of 1.0 m/s. All samplings were done at night. After zooplankton collections, samples were immediately preserved in 5% buffered formalin. At a laboratory, a plankton splitter was used to divide samples into subsamples (Motoda, 1959), depending on abundance, and a dissecting microscope was used to count the number of zooplankton in each taxonomic group. Copepods were identified to species level as far as possible.

Dominant species of copepods were determined as follows (Hosokawa *et al.*, 1968):

$$\text{Dominant species } N_i > (1/S)\ \Sigma\ N_i$$

where Ni indicates the number of *i*th species, and S means total number of species. Similarity indices among each station were calculated to access the copepod assemblages. Then a Percent Similarity Index (PSI) was adopted as follows (Schoener, 1970):

$$PSI = 1.0 - 0.5\Sigma\ |\ P_{ij} - P_{hj}\ |$$

where Pij and Phj mean the ratio of species j at station i and h, respectively. Based on the PSI, cluster analysis was done by a single linkage clustering method.

Results

Hydrography

In mid-April, water shallower than 20 m depth was occupied by less saline Okhotsk Surface Water (OSW) indicated by salinity of < 32.5 (Fig. 2). Cold Intermediate Water (CIW) underlying the OSW was recognized in which water temperature was less than 2°C and salinity was around 33.0 at stations beyond O33. Water temperature at Stns. O31 and O32 reached 8–10°C in early June, coinciding with high saline water, the Soya Warm Current (SWC), having a salinity of >33.6. CIW was found at stations beyond O34. Water temperature in coastal areas increased 10 to 14°C in late July. The SWC was found below 10 m depth at Stn. O32. CIW occupied the layer below about 40 m depth at stations beyond O33. Throughout the investigations, the fronts of the CIW were observed between Stns. O32 and O33 in mid-April and late July, and between Stns. O33 and O34 in early June.

Total zooplankton abundance and copepod dominance

The maximum of total zooplankton abundances (1,864 inds. m^{-3}) was found at Stn. O31 in early June, and the minimum (43 inds. m^{-3}) was observed at Stn. O35 also in early June (Fig. 3). Average abundances decreased toward July. Throughout the investigations, copepods occupied more than 90% of the composition, except for at Stn. O31 in early June and late July when Cladocera or Appendiculata were predominant at the coastal stations. Twenty genera and twenty five species could be identified, except for one calaniod species (Table 1). Copepods were composed of mostly cold water species. In these species, seven species such as *Neocalanus* spp. other than *Neocalanus cristatus*, *Pseudocalanus minutus*, *Pseudocalanus newmani*, *Metridia pacifica*, *M. okhotensis*, *Acartia longiremis* and *Oithona similis* were determined as dominant species throughout investigations.

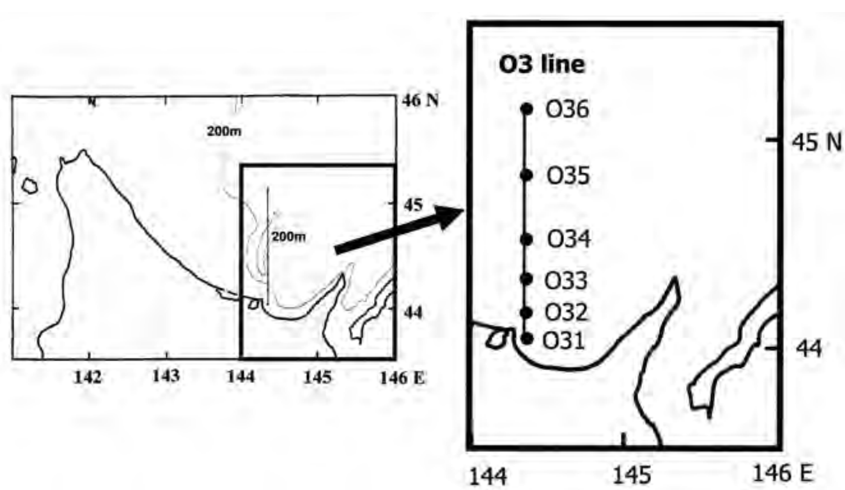

Fig. 1 Study sites and zooplankton sampling stations during mid-April to late July 2002 in the Okhotsk Sea off eastern Hokkaido.

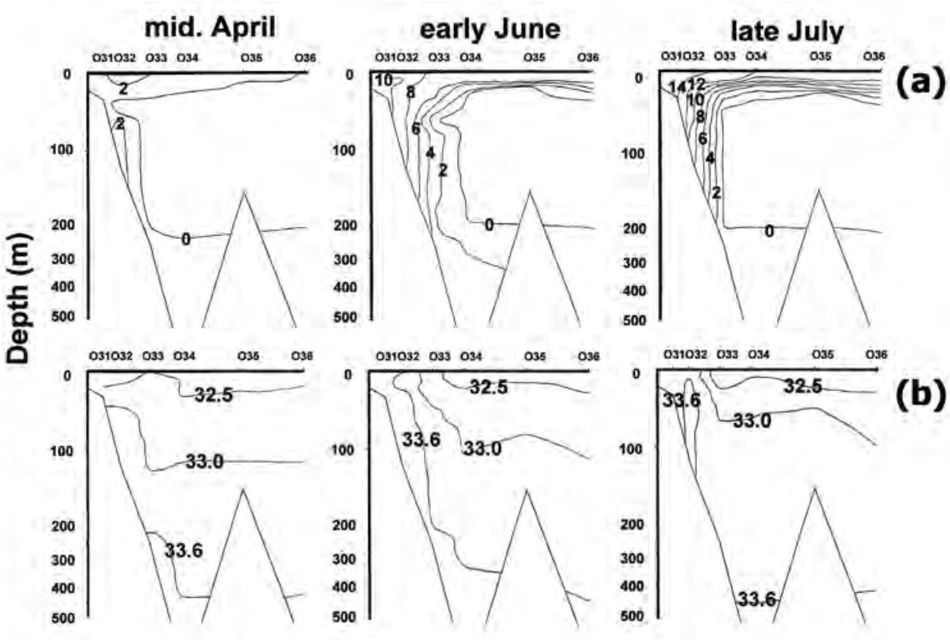

Fig. 2 Transect profiles of (a) water temperature and (b) salinity at O3 line in 2002.

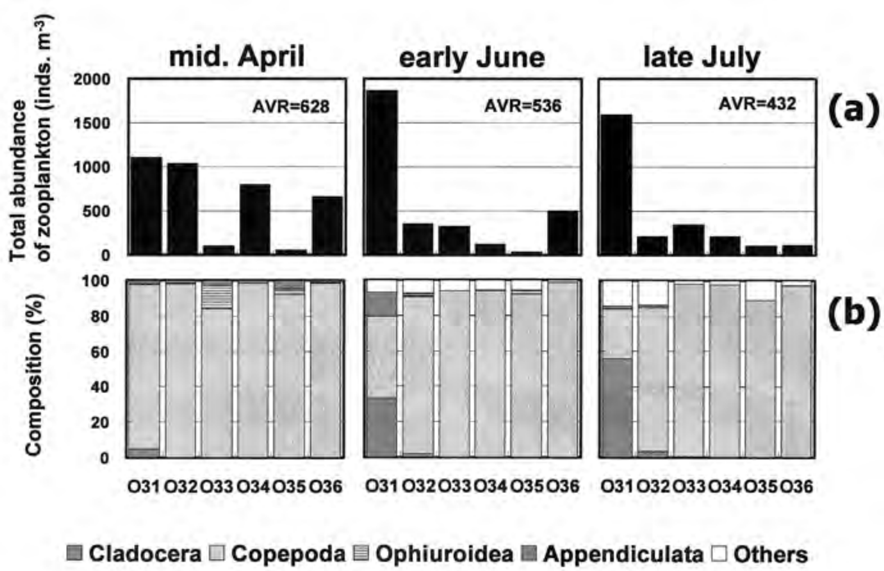

Fig. 3 (a) Total zooplankton abundances and (b) their dominant taxonomic compositions, at O3 line in 2002.

Table 1 List of copepod species observed during the investigations.

Calanoida	
●	*Calanus glacialis* Jaschenov
○	*Calanus pacificus* Brodsky
●	*Neocalanus cristatus* (Kroyer)
●	*Neocalanus* spp.
○	*Mesocalanus tenuicornis* (Dana)
□	Calanidae
●	*Eucalanus bungii* Giesbrecht
○	*Paracalanus parvus* (Claus)
●	*Pseudocalanus minutus* (Kroyer)
●	*Pseudocalanus newmani* Frost
●	*Microcalanus pygmaeus* (Saras)
○	*Clausocalanus pergens* Farran
△	*Aetideopsis* sp.
○	*Gaetanus armiger* Giesbrecht
●	*Paraeuchaeta elongate* (Easterly)
●	*Scolecithricella minor* Brady
●	*Eurytemora herdmani* Thompson & Scott
●	*Metridia pacifica* Brodsky
●	*Metridia okhotskensis* Brodsky
●	*Centropages abdominalis* Sato
●	*Acartia longiremis* (Lilljeborg)
●	*Tortanus discaudatus* Thompson & A. Scott
Cyclopoida	
●	*Oithona atlantica* Farran
●	*Oithona similes* Claus
Harpacticoida	
△	*Microsetella norvegica* (Boeck)

● Cold water species; ○ Warm water species; △ Eurythermic species; □ Not clear

Species composition and assemblages of copepods in relation to hydrography

Average abundances of copepods were the highest in mid-April, in spite of extremely low abundances at Stns. O33 and O35 (Fig. 4a). *P. newmani* made up 80–87% at Stns. O31 and O32 in mid-April (Fig. 4b). *M. pacifica*, *M. okhotensis* and *Neocalanus* spp. were the main components at stations beyond O33. *M. pacifica* made up 46% at Stn. O33 and 68% at Stn. O36, respectively. *M. okhotensis* occupied 67% at Stn. O34 and 30% at Stn. O36, respectively. *P. newmani* dominated from Stns. O31 to O33 in early June, and it made up 62–91% of total copepod abundances. *M. pacifica* and *M. okhotensis* were predominant in addition to *P. newmani* at Stns. O34 and O35. The composition of *M. okhotensis* reached 94% at Stn. O36. *A. longiremis* made up 93% at Stn. O31 in late July. *P. newmani* was predominant in addition to *A. longiremis* at Stn. O32. At stations beyond O33, *M. okhotensis* dominated, making up 30–70% of total copepod abundances.

As a result of cluster analysis based on PSI, three assemblages were recognized by fitting a 0.5 PSI in each month (Fig. 5). At the boundary front of CIW, one assemblage (assemblage 1) in mid-April and early June, and two assemblages (assemblages 1 and 2) in late July were observed in the coastal stations. These groups were composed of *P. newmani* or *A. longiremis* (*cf.*, Fig. 4b). Two assemblages (assemblages 2 and 3) were observed in mid-April and early June (Fig. 5). In these assemblages, at stations far from the front (assemblage 3), the main components were *M. okhotensis* or *M. pacifica* (*cf.*, Fig. 4b). Dominant species in assemblage 2 consisted of mixtures with assemblages 1 and 3 (*cf.*, Fig. 4b). Although *M. okhotensis* was one of the dominant species in assemblage 3 in late July, *P. newmani* was also an important component in this group (*cf.*, Fig. 4b). Because *P. newmani* was predominant in assemblage 2 in late July, the species composition of assemblage 3 might be mixed with assemblage 2.

Figure 6 shows the abundances of dominant species in each month. At the boundary of the CIW, the distributional characteristics are divided into three types. The coastal type composed of *P. newmani* and *A. longiremis* tended to distribute clearly in coastal areas. Four species, such as *Neocalanus* spp., *P. minutus*, *M. pacifica* and *O. similis* distributed in both coastal and pelagic stations, although two species of *Neocalanus* spp. and *P. minutus* were abundant in coastal stations in middle April. Distributions of *M. okhotensis* were limited beyond the front, and contributed to pelagic type.

Discussion

Different water properties, such as the Soya Warm Current (SWC), less saline Okhotsk Surface Water (OSW) and the Cold Intermediate Water (CIW) are known in the Okhotsk Sea (Takizawa, 1982). The dynamics of the SWC from spring to summer affected zooplankton variability along nearshore waters of the Okhotsk Sea, eastern Hokkaido (Asami

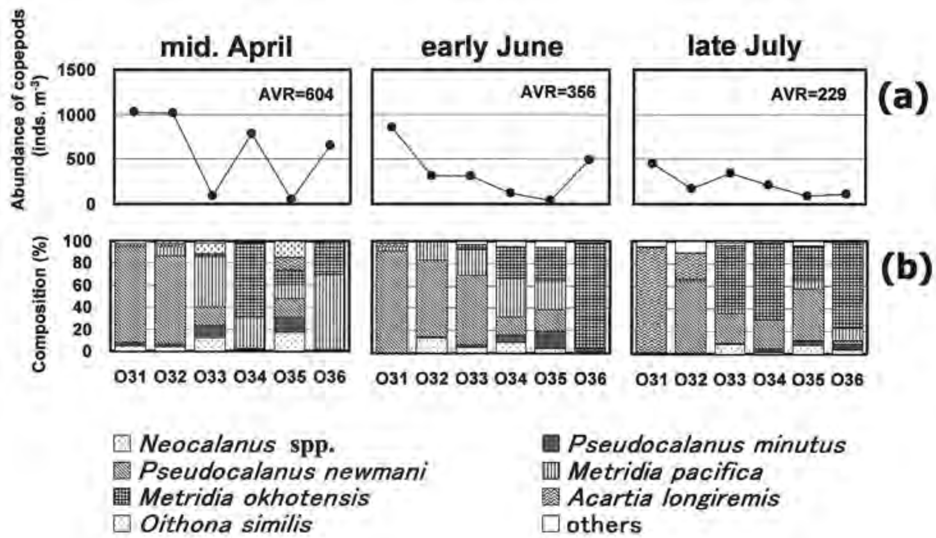

Fig. 4 Total abundance of (a) copepods and (b) their dominant species composition at O3 line in 2002.

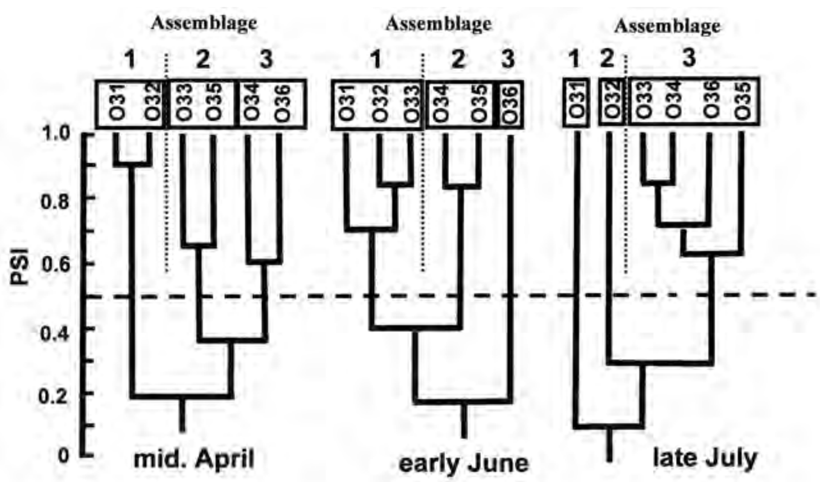

Fig. 5 Cluster analysis of copepod assemblages based on the PSI index. Dotted line indicates the front of the CIW.

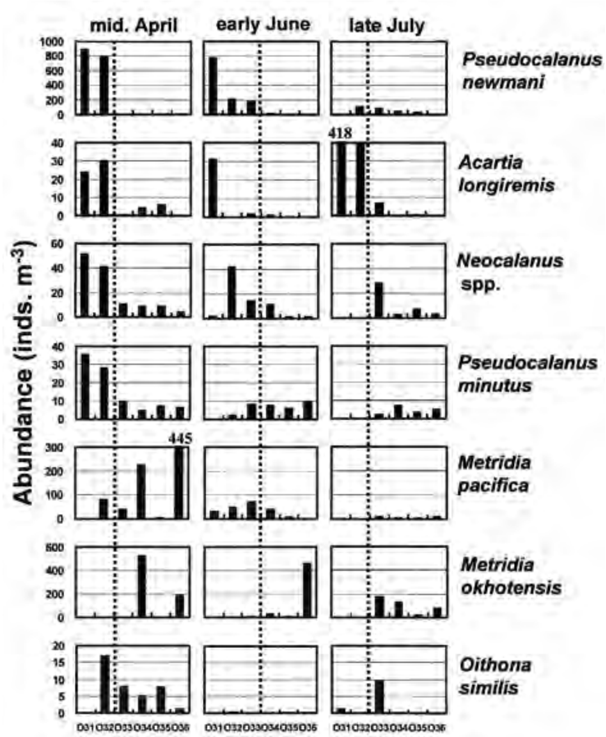

Fig. 6 Abundances of dominant copepod species related to the front of the CIW at O3 line in 2002. Dotted lines indicate the front of the CIW.

et al., 2007). Although some studies have dealt with the vertical and horizontal distributions of zooplankton in the Okhotsk Sea (Vinogradov, 1954; Takeuchi, 1972), there is little information for the horizontal distributions of zooplankton related to the CIW. The present study suggests that spatial distributions of copepods in offshore areas relate to the extension of the CIW. At the boundary of the front of the CIW, *P. newmani* was the most abundant copepod in coastal areas. In the Oyashio region of southwestern Hokkaido, *P. newmani* peaked in abundances after the spring blooms emerged and abundances decreased when water temperature reached 15°C (Yamaguchi and Shiga, 1997). Since the abundances of *P. newmani* decreased when coastal water temperature reached >14°C in this study, seasonal distributions of *P. newmani* might strongly depend on water temperature. *Neocalanus* spp., *P. minutus*, *M. pacifica* and *O. similis* were dominant species in assemblages mixed with coastal and pelagic assemblages. Among these species, the seasonal distributions of *Neocalanus* spp. and *P. minutus* seemed to relate to the movements of the SWC because these species tended to be abundant in coastal areas in mid-April when the SWC did not appear. However their distributions shifted toward pelagic areas when the SWC was found in the coastal areas in early June and late July. *Neocalanus* spp. are known as the important prey organisms of juvenile chum salmon (Simenstad and Salo, 1982; Nagata *et al.*, 2007). Spatial distributions of *Neocalanus* spp. may be important factors in taking account of the offshore migrations of juvenile chum salmon.

M. okhotensis was the most dominant species and appeared in pelagic areas affected by the CIW during the investigations. According to the reviews by Pinchuk and Paul (2000), *M. okhotensis* distributed in the depth below thermocline where water temperature decreased from 10 to 0°C sharply in northern Okhotsk Sea in summer. The fine vertical distribution related to the CIW must be also studied in southern Okhotsk Sea along Hokkaido. Biomass of *M. okhotensis* occupied more than 30 to 80% during spring to summer (Asami *et al.*, unpublished data). Since *M. okhotensis* also makes active diel vertical migrations (Vinogradov, 1954; Hattori, 1989), it is thought that *M. okhotensis* plays an important role in carbon dynamics of ecosystems, and more detailed research efforts are required in the Okhotsk Sea.

Acknowledgements

We thank the efforts in samplings given by officers and crew of the R/V *Hokuyo Maru*. We also thank Mr. M. Iwabuchi of Econixe Co., Ltd. for his support of species identifications.

References

Asami, H., Shimada, H., Sawada, M., Sato, H., Miyakoshi, Y., Ando, D., Fujiwara, M. and Nagata, M. 2007. Influence of physical parameters on zooplankton variability during early ocean life of juvenile chum salmon in the coastal waters of eastern Hokkaido, Okhotsk Sea. *N. Pac. Anadr. Fish Comm. Bull.* **4**: 211–221.

Blaxter, J.H.S. and Hunter, J.R. 1982. The biology of the clupeoid fishes. *Adv. Mar. Biol.* **20**: 1–323.

Hattori, H. 1989. Bimodal vertical distribution and diel migration of the copepods *Metridia pacifica*, *M. okhotensis* and *Pleuromamma scutullata* in the western North Pacific Ocean. *Mar. Biol.* **103**: 39–50.

Hosokawa, T., Kato, M., Kitazawa, Y., Nomura, K., Taguchi, R., Torii, Y. and Yagi, S. 1968. An Introduction to Ecology. Yokendo, Tokyo (in Japanese).

Irie, T. 1990. Ecological studies on the migration of juvenile chum salmon, *Oncorhynchus keta*, during early life. *Bull. Seikai Natl. Fish. Res. Inst*. **68**: 1–142 (in Japanese with English abstract).

Kamba, M. 1977. Feeding habits and vertical distribution of walleye pollock, *Theragma chalcogramma* (Pallas), in early life stage in Uchiura Bay, Hokkaido. *Res. Inst. N. Pac. Fish.,* Hokkaido Univ. Spec. Vol., pp. 175–197.

Mauchline, J. 1998. The biology of calanoid copepods. *Adv. Mar. Biol*., **33**: 1–170.

Motoda, S. 1959. Devices of simple plankton apparatus. *Mem. Fac. Fish. Hokkaido Univ*. **7**: 73–94.

Motoda, S. and Sato, S. 1949. The food of the spring Atka-fish (*Pleurogrammus azonus*) with its hydrographic bearing. *Nipponsuisangakkaishi* **15**: 343–353 (in Japanese with English abstract).

Nagata, M., Miyakoshi, Y., Ando, D., Fujiwara, M., Sawada, M., Shimada, H. and Asami, H. 2007. Influence of coastal seawater temperature on the distribution and growth of juvenile chum salmon, with recommendations for altered release strategies. *N. Pac. Anadr. Fish Comm. Bull*. **4**: 223–235.

Pearcy, W.G. 1992. Ocean Ecology of North Pacific Salmonids. Washington Sea Grant Program, University of Washington Press, Seattle, WA.

Pinchuk, A.I. and Paul, A.J. 2000. Zooplankton of the Okhotsk Sea: a review of Russian studies. University of Alaska Sea Grant College Program, Fairbanks, AK.

Schoener, T.W. 1970. Nonsynchronous spatial overlap of lizards in patchy habitats. *Ecology* **51**: 408–418.

Simenstad, C.A. and Salo, O. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington. pp. 21–37, Proceedings of the North Pacific Aquaculture Symposium, Anchorage, AK.

Takeuchi, I. 1972. Food animals collected from the stomachs of three salmonid fishes (*Oncorhynchus*) and their distribution in the natural environments in the northern North Pacific. *Bull. Hokkaido Reg. Res. Lab*. **38**: 1–118 (in Japanese with English abstract).

Takizawa, T. 1982. Characteristics of the Soya Warm Current in the Okhotsk Sea. *J. Oceanogr. Soc. Japan* **38**: 281–292.

Vinogradov, M.E. 1954. Diurnal vertical migrations of zooplankton in the far-eastern seas. *Tr. IOAN* **8** (quoted from Vinogradov, M.E. 1972).

Yamaguchi, A. and Shiga, N. 1997. Vertical distributions and life cycles of *Pseudocalanus minutus* and *P. newmani* (Copepoda; Calanoida) off Cape Esan, southwestern Hokkaido. *Bull. Plankton Soc. Japan* **44**: 11–20 (in Japanese with English abstract).