Title	Seasonal changes in zooplankton community structure in Ishikari Bay, Japan Sea
Author(s)	Arima, Daichi; Yamaguchi, Atsushi; Abe, Yoshiyuki; Matsuno, Kohei; Saito, Rui; Asami, Hiroki; Shimada, Hiroshi; Imai, Ichiro
Citation	北海道大学水産科学研究彙報, 64(1): 17-23
Issue Date	2014-03-14
Doc URL	http://hdl.handle.net/2115/54866
Right	
Type	bulletin (article)
Additional Information	

Bull. Fish. Sci. Hokkaido Univ.
64(1), 17-23, 2014.

Seasonal changes in zooplankton community structure in Ishikari Bay, Japan Sea

Daichi ARIMA[1)], Atsushi YAMAGUCHI[1)], Yoshiyuki ABE[1)], Kohei MATSUNO[1)2)], Rui SAITO[1)3)], Hiroki ASAMI[4)],
Hiroshi SHIMADA[4)] and Ichiro IMAI[1)]

(Received 2 December 2013, Accepted 16 December 2013)

Abstract

Seasonal changes in the zooplankton community in Ishikari Bay, northern Japan Sea were studied based on monthly samples collected by vertical hauls of a 100 μm mesh NORPAC net from March 2001 to May 2002. Zooplankton abundance peaked in May and was mainly composed of copepodid stages of copepods. Cluster analysis of copepod abundance separated the community into two main groups : group A was observed from January to June (winter and spring) and group B from July to December (summer and autumn). Groups A and B were composed of cold and warm water species, respectively. Species diversity was high for group B. As the second dominant taxa, copepod nauplii dominated during winter and spring, whereas molluscs and appendicularians were abundant during summer and autumn. Copepod nauplii in winter and spring likely reflect the copepod reproduction initiated by spring the phytoplankton bloom. Molluscs in summer and autumn were composed of planktonic larvae of benthos (=meroplankton). Appendicularians during summer and autumn are oceanic and considered to have been transported by the Tsushima warm current. High copepod species diversity during summer and autumn might also be related to the Tsushima warm current.

Key words : Mesozooplankton, Community, Species diversity, Copepods, Nauplii, Appendicularians, Molluscs, Tsushima warm current

Introduction

Zooplankton are important prey for larvae of various commercially important fishes (e.g., herring, capelin, walleye pollock and cod) in high-latitude coastal waters (Pedersen and Fossheim, 2008 ; Logerwell et al., 2010). Studies have shown that the amount of food available is an important determinant of fish survival ; i.e., walleye pollock in the southeastern Bering Sea (Brodeur et al., 2000 ; Ciannelli et al., 2004) and in Funka Bay (Kendall and Nakatani, 1992). Information on zooplankton abundance, biomass and community structure is essential to evaluate the survival of fish larvae.

Ishikari Bay is located in the northern Japan Sea. Hydrography of the Japan Sea is characterised by a two-layer system ; the surface layer is strongly affected by the Tsushima warm current, and the deep layer has a highly saline and low-temperature water mass (Zenkevitch, 1963). Ishikari Bay has a moderate slope down to approximately 100 m, with a steep slope down to 700 m. Because of this bathymetric feature, coastal upwelling and vertical mixing in winter are the major sources of nutrient supply to the surface layer (Yoshida et al., 1977 ; Yamashita et al., 2004). The Ishikari River, the largest river on Hokkaido, flows into Ishikari Bay and provides sufficient nutrients to the estuarine region (Yoshida et al., 1977), making Ishikari Bay highly productive and an important fishing ground for species such as salmon, herring, walleye pollock and flounder (Hayashi, 1980). Zooplankton in Ishikari Bay has been studied for a long time, and information on the large taxa dominating the biomass has accumulated (Anraku, 1953 ; Motoda, 1971 ; Kotori, 1977 ; Asami et al., 2010). However, there remains a need to assess the zooplankton community, especially the numerically dominant small taxa that are important food for larval fish.

The present study aims to evaluate seasonal changes in small zooplankton taxa based on fine mesh (100 μm) net samples collected in Ishikari Bay at 1-2 month intervals between March 2001 and May 2002. From the samples, seasonal changes in zooplankton abundance, biomass, com-

---

[1)] *Laboratory of Marine Biology, Graduate School of Fisheries Science, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan (e-mail : d-arima@fish.hokudai.ac.jp)*
(北海道大学大学院水産科学研究院海洋生物資源科学部門海洋生物学分野浮遊生物学領域)
[2)] *Present address : Arctic Environmental Research Center, National Institute of Polar Research, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan*
(現所属：国立極地研)
[3)] *Present address : Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8564, Japan*
(現所属：東大大気海洋研)
[4)] *Hokkaido Research Organization, Central Fisheries Research Institute, 238 Hamanaka-cho, Yoichi, Hokkaido 046-8555, Japan*
(道総研中央水産試験場)

munity structure and species diversity were evaluated. We discuss what factors control the seasonal changes of small zooplankton taxa.

Materials and Methods

Field sampling

One or two month interval samplings were conducted at four stations (J3A, J31, J32 and J33) in Ishikari Bay from 12 March 2001 to 14 May 2002 (a total of twelve times) (Fig. 1). Zooplankton samples were collected by vertical hauls of NORPAC nets (45 cm mouth diameter, 100 µm mesh ; Motoda, 1957) from near the bottom to the surface. A flowmeter (Rigosha Co. Ltd.) mounted on the net ring enabled quantification of the filtered water volume. Zooplankton samples were immediately preserved with 5% formaldehyde-seawater.

Water temperature and salinity were measured by CTD (Seabird SBE911) casts during each sampling. In addition, at all stations except J33, 300-ml sea water samples were collected at 5- or 10-m intervals by Nansen bottle or bucket at the surface and filtered through GF/F filters. The filters were then immersed in 90% acetone in dark conditions for a day, and the chlorophyll *a* (Chl. *a*) concentration was measured using a fluorometer (Turner Model 10AU).

Sample analysis

Zooplankton samples were divided into two subsamples using a Motoda plankton splitter (Motoda, 1959), and wet mass (WM) was measured for each subsample. Samples at J3A, J32 and J33 were sorted and counted, with each zooplankton taxonomic group identified under a stereomicroscope. For the 1/5-1/30 subsamples (made using a wide-bore pipette) at St. J31, identification and enumeration of copepod species and copepodid stages were made under a stereomicroscope or inverted microscope. However, because of difficulties in species identification for the genera *Oncaea* and *Corycaeus*, they were treated as *Oncaea* spp. and *Corycaeus* spp., respectively. Identification of copepod species followed Brodsky (1967) and Ohtsuka et al. (1997). Nauplii were unidentified to species and grouped as 'copepod nauplii', and the copepodid stages were identified to species as much as possible. For copepodid stages of *Oithona*, we referred to Uchima (1979).

Data analysis

Abundance data of copepods (X : ind. m^{-3}) for each species were $\log_{10}(X+1)$ transformed prior to cluster analysis in order to reduce the bias of abundance. Similarities between samples were examined using the Bray-Curtis index, according to the differences in species composition. Samples with similar species composition were grouped using hierarchical agglomerative clustering, based on a complete linkage method (Unweighted Pair Group Method using Arithmetic mean : UPGMA) (Field et al., 1982). This cluster analysis was performed using Primer 6 software. Species diversity index (H'), based on copepod abundance, was calculated using the equation :

$$H' = -\sum n/N_i \times \ln n/N_i \qquad (1)$$

where n is the abundance (ind. m^{-3}) of ith species, and N_i is the total copepod abundance (ind. m^{-3}) in the group (Shannon and Weaver, 1949).

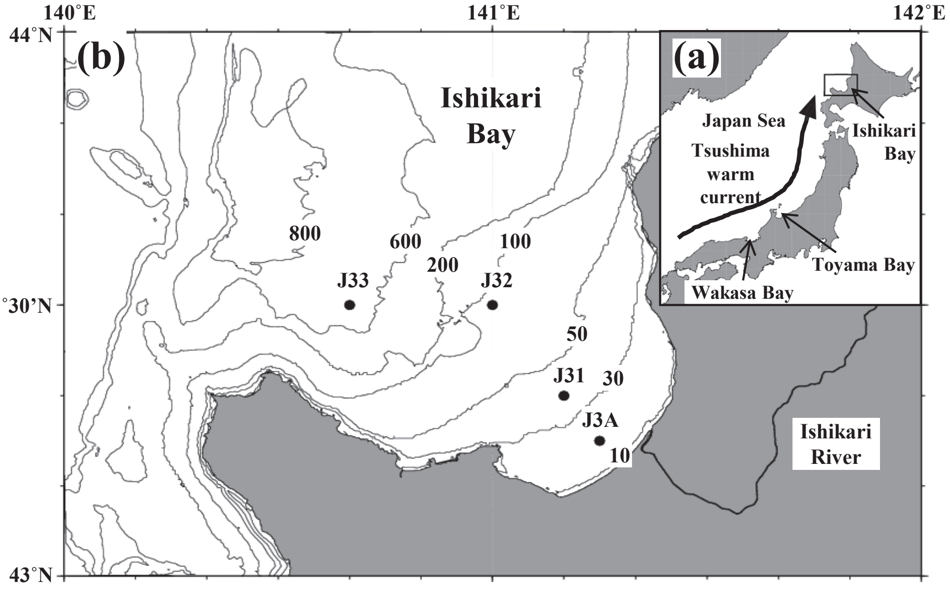

Fig. 1. Location of Ishikari Bay in Japan Sea (a). Sampling stations (J3A, J31, J32 and J33) in Ishikari Bay (b). Location of the other bays where copepod fauna have been studied in Japan Sea is shown in (a). Depth contours (10, 30, 50, 100, 200, 600 and 800 m) are superimposed in (b).

Results

Hydrography

Fig. 2 shows seasonal changes in the T–S diagram and the integrated mean temperature, salinity, Chl. *a* and zooplankton wet mass at J3A, J31, J32 and J33. At all stations, salinity showed little seasonality, and temperature had a clear seasonal pattern : <15°C at sea surface from February to June and >20°C from July to December. Integrated mean salinity was low (33.1–33.9 PSU) at coastal station J3A and gradually increased with offshore stations.

At all stations, Chl. *a* had a peak during March to April (Fig. 2). The maximum value was higher at coastal stations : 6.0 mg m^{-3} at J3A, 3.8 mg m^{-3} at J31 and 1.9 mg m^{-3} at J32. At the near-coastal station (J3A), in addition to the spring peak, there were additional high concentrations during September to December (Fig. 2a). At the offshore stations (J31 and J32), Chl. *a* had a peak only in the spring period (Fig. 2b, c).

Zooplankton biomass showed minimal station-specific differences (peaks ranged between 2.3 and 2.9 g WM m^{-3}). Seasonal changes in zooplankton biomass were similar to those of Chl. *a* ; higher values occur from March to April 2001 and at the more coastal station (J3A) when compared to the offshore stations (Fig. 2).

Zooplankton community

Seasonal changes in total zooplankton abundance and taxonomic composition at J3A, J32 and J33 are shown in Fig. 3. At all stations, zooplankton abundance peaked in May, which was one or two months later than the biomass peak (March or April) (Fig. 3a). The maximum value for zooplankton abundance was 55,454 ind. m^{-3}, recorded at J3A. Throughout the year, zooplankton abundance was higher at the coastal station (J3A) than at the offshore stations (J32 and J33) (Fig. 3a).

Taxonomic composition in abundance was dominated by copepods, which composed 50–80%, except during September 2001 and May 2002 at J3A. In addition to copepods, copepod nauplii (3–45%), appendicularians (0.04–37%) and molluscs (0.09–39%) were also dominant (Fig. 3b, c, d). Taxonomic composition showed little station-specific difference, and there were common seasonal changes : copepod nauplii were dominant from February to June, and appendicularians and molluscs were proportionally more abundant from July to December.

Throughout the study period, a total of 22 genera and 31 copepod species occurred at J31 (Table 1). Cluster analysis based on copepod abundance separated the community at J31 into two large groups (group A and B, Fig. 4a). Occurrence of each group showed clear seasonality : group A was observed from January to June and group B was observed from July to December. Group C was composed of only one sample from March 2001. Because of the extremely low abundance, group C was considered to be an out-group (Fig. 4b). Copepod abundance had a maximum (16,347 ind. m^{-3}) in May 2001, similar to that of total zooplankton (Fig. 4b). Species diversity (*H'*) was higher from September to December, and values of group B were significantly higher than those of group A ($p < 0.05$, *U*-test). Copepod species composition also showed clear seasonality. Group A was mainly composed of cold-water species (*Pseudocalanus* spp. and *Oithona* spp.), whereas group B was dominated by warm-water species (*Clausocalanus pergens*, *Paracalanus parvus*, *Calanus pacificus* and other warm-water copepods) (Fig. 4c, Table 1).

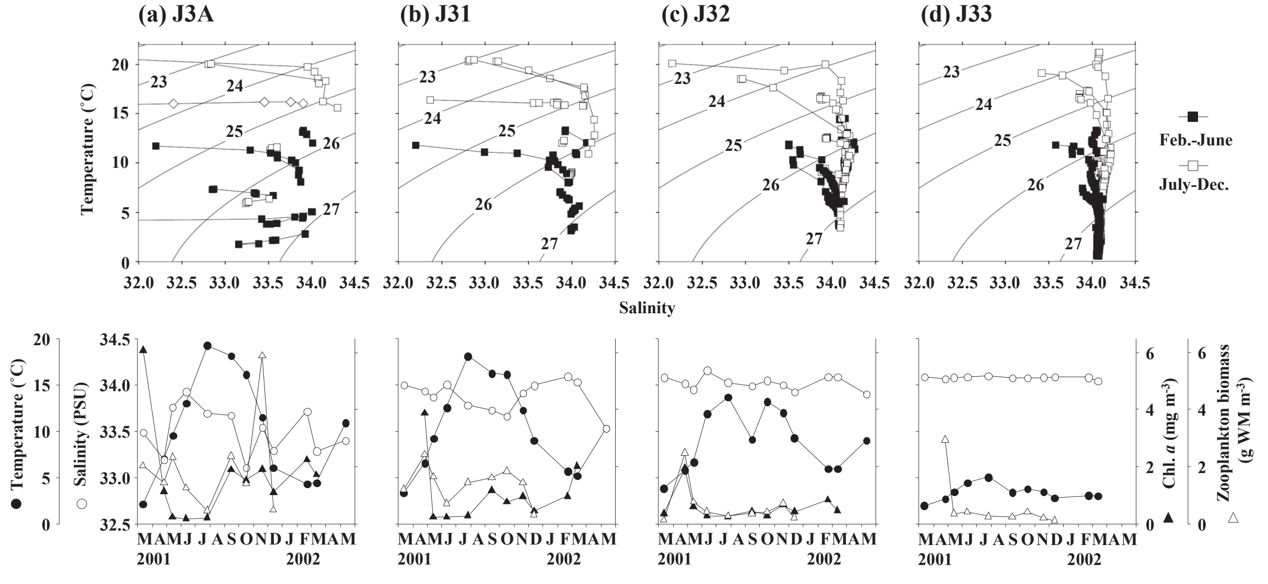

Fig. 2. Seasonal changes in T–S diagram (upper panels) and depth integrated mean temperature, salinity, Chl. *a* and zooplankton biomass (lower panels) at J3A (a), J31 (b), J32 (c) and J33 (d) in Ishikari Bay from March 2001 to May 2002.

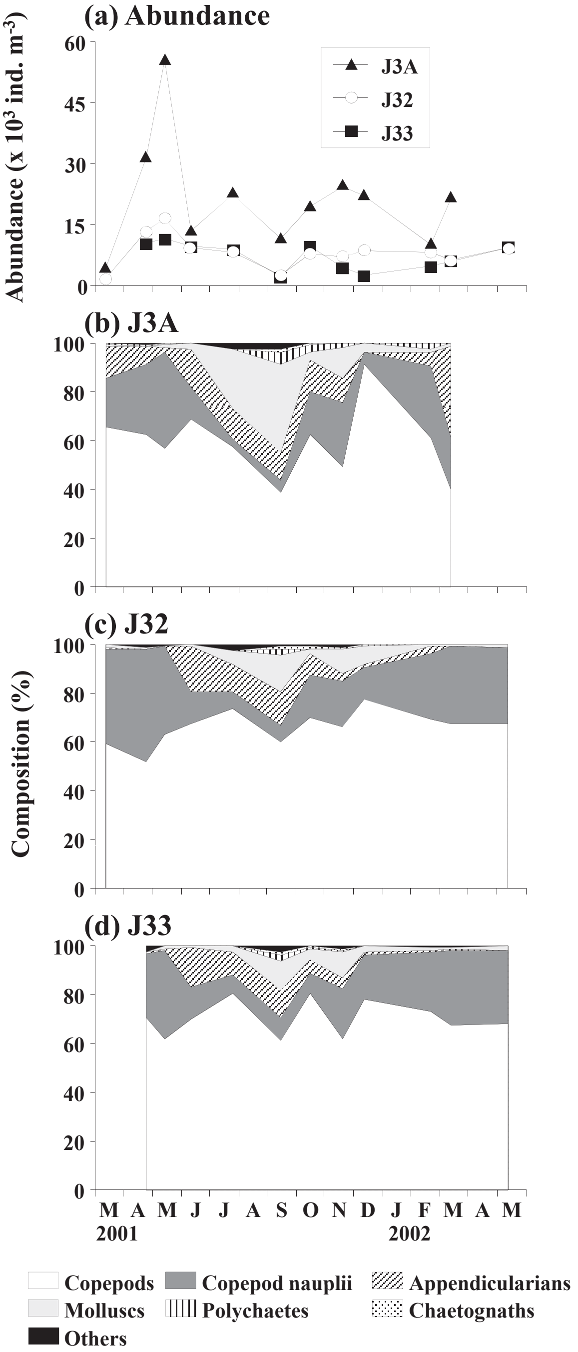

Fig. 3. Total zooplankton abundance (a) and their taxonomic composition at J3A (b), J32 (c) and J33 (d) in Ishikari Bay from March 2001 to May 2002.

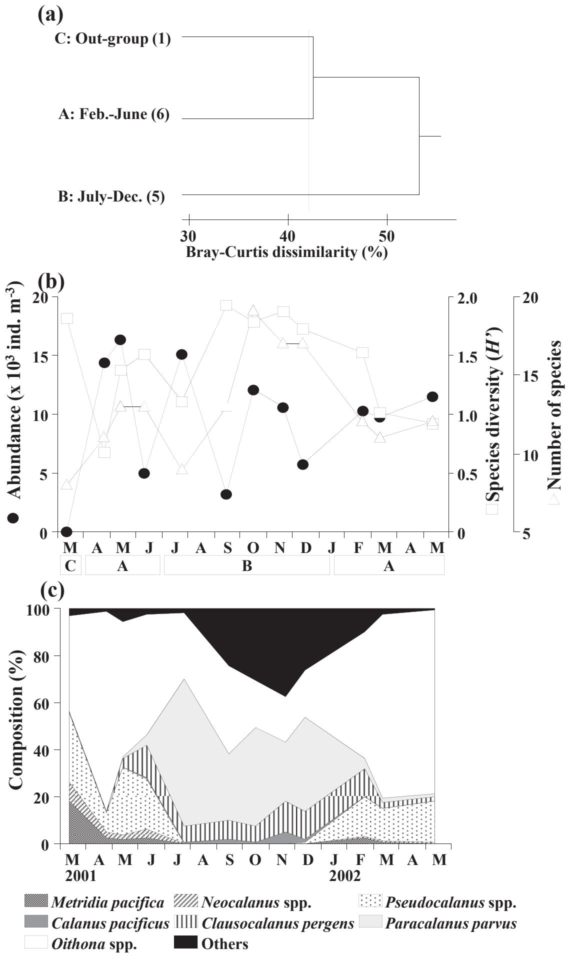

Fig. 4. Results of cluster analysis based on copepod abundance (a), seasonal changes in total copepod abundance, clustered groups, species diversity and number of species (b) and copepod species composition (c) at J31 in Ishikari Bay from March 2001 to May 2002. Three groups (A, B and C) were clustered at 42% dissimilarity (dashed line in a). Numbers in parentheses in (a) indicate samples included in each group.

Discussion

Maximum zooplankton abundance in this study was 55,454 ind. m^{-3}. Previously reported maximum zooplankton abundance in Ishikari Bay was between 1,175–2,177 ind. m^{-3} (Asami et al., 2010). These previous values were nearly one-twentieth of those of this study. These differences in abundance are considered to be a result of the differences in net mesh sizes. Asami et al. (2010) used a 335 μm mesh net, and we used a 100 μm mesh net. The finer mesh size enabled a more effective collection of smaller zooplankton, such as copepod nauplii during their peak abundance period (May). Maximum zooplankton biomass was 2.9 g WM m^{-3} in this study. Kotori (1983), using a 335 μm net, reported a maximum zooplankton biomass of 4.3 g WM m^{-3} in Ishikari Bay. Thus, zooplankton biomass did not vary markedly with the mesh sizes. This is a result of the zooplankton biomass being determined primarily by the abundance of the large-sized copepods, which may not vary with changes in the mesh size (100 μm or 335 μm).

This study shows that copepod nauplii dominated the zooplankton community in Ishikari Bay during winter and spring, and appendicularians and molluscs were dominant during summer and autumn (Fig. 3b–d). Dominance of nauplii from winter to spring may have been caused by copepods

Table 1. List of copepod species identified in Ishikari Bay during March 2001 to May 2002. Regarding species characteristics, their habitat temperature (warm, cold and eurythermal ; cf. Hirakawa et al., 1990 ; Ohtsuka et al., 1997), maximum abundance and period are shown. Normal and bold lines indicate that the composition to total abundance was low (<20%) and high ($\geq$ 20%), respectively.

Habitat temp.	Species	Maximum abundance (ind. m^{-3})	2001										2002				
			M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
	Calanoida																
W	*Acartia danae*	15 (Oct. '01)								—	—						
W	*Acrocalanus gibber*	19 (Dec. '01)										—					
W	*Acrocalanus gracilis*	19 (Nov. '01)									—						
W	*Calanus pacificus*	525 (Nov. '01)				—	—	—	—	—	—						
W	*Calocalanus pavo*	15 (Oct. '01)								—							
W	*Candacia bipinnata*	3 (Dec. '01)										—					
W	*Centropages bradyi*	403 (Oct. '01)							—	—	—	—					
W	*Centropages tenuiremis*	147 (Nov. '01)								—	—						
W	*Clausocalanus pergens*	1,440 (Nov. '01)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W	*Eucalanus attenuatus*	8 (Oct. '01)		—						—							
W	*Mesocalanus tenuicornis*	131 (Feb. '02)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W	*Nannocalanus minor*	8 (Oct. '01)		—						—							
W	*Paracalanus aculeatus*	19 (Nov. '01)									—						
W	*Paracalanus parvus*	9,255 (July '01)			—	—	━	━	━	━	━	—	—	—	—	—	—
W	*Temora discaudata*	30 (Oct. '01)							—	—							
C	*Metridia pacifica*	433 (Apr. '01)	—	—	—	—								—	—	—	—
C	*Neocalanus flemingeri*	57 (May '01)	—	—	—	—								—	—	—	—
C	*Neocalanus plumchrus*	296 (Apr. '01)	—	—	—	—								—	—	—	—
C	*Pseudocalanus minutus*	787 (May '01)	—	—	—	—								—	—	—	—
C	*Pseudocalanus newmani*	3,862 (May '01)	━	—	━	—	—					—	—	—	—	—	—
C	*Scolecithricella dentata*	8 (Oct. '01)								—							
C	*Tortanus discaudatus*	78 (May '02)				—			—								—
	Cyclopoida																
W	*Oithona nana*	442 (Nov. '01)							—	—	—	—					
W	*Oithona plumifera*	26 (Dec. '01)								—	—	—					
C	*Oithona atlantica*	497 (July '01)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	*Oithona similis*	12,110 (Apr. '01)	━	━	━	━	━	━	━	—	—	—	—	━	━	━	━
	Harpacticoida																
W	*Euterpina acutifrons*	30 (Oct. '01)							—	—	—						
E	*Microsetella norvegica*	1,262 (Oct. '01)			—	—	—	—	—	—	—			—			
	Harpacticus spp.	5 (May '01)			—									—			
	Poecilostomatoida																
	Corycaeus spp.	326 (Nov. '01)							—	—							
	Oncaea spp.	2,643 (Nov. '01)		—	—	—	—	—	—	—	━	━	—	—	—		

utilising a phytoplankton bloom as energy for reproduction (Fig. 2). In Toyama Bay, located in the southern Japan Sea, reproduction of zooplankton (copepods or euphausiids) is initiated by the phytoplankton bloom during winter and spring (Hirakawa and Imamura, 1993 ; Yamaguchi et al., 1998 ; Iguchi and Ikeda, 1999). In this study, the biomass peak of zooplankton was observed in March or April (Fig. 2a–d), and the abundance peak was observed one or two months later (Fig. 3a). These results suggest that the biomass and abundance peaks correspond and are composed of adults (biomass peak in March to April) and recently reproduced larvae (abundance peak one–two months later), respectively.

Molluscs during summer and autumn were composed of planktonic larvae (meroplankton) of benthic bivalves or snails. Mollusc larvae have also been observed to be an important component of the summer and autumn zooplankton community in various high–latitude regions (Highfield et al., 2010 ; Ayata et al., 2011). In contrast, appendicularians are known to be oceanic taxa, and their dominance during summer and autumn might be related to the strength of the Tsushima warm current (Fig. 2). In Toyama Bay, located south of Ishikari Bay, the appendicularian *Oikopleura longicauda* is abundant and reproduces in summer (Tomita et al., 1999). Because the vertical distribution of *O. longicauda* is shallow (Tomita et al., 2003), this species may dominate during summer and autumn when the strength of the Tsushima warm current is strong. Minoda et al. (1979) also reported that *O. longicauda* did not occur in Ishikari Bay during April and May, and *O. longicauda* was transported into the bay in June by the Tsushima warm current and dominated the zooplankton community during summer.

High species diversity of copepods during summer and autumn (Fig. 4b) might also be related to the strength of the Tsushima warm current. Because the straits connected with the North Pacific are shallow (<130 m), zooplankton fauna in the Japan Sea lack cold water species, especially deep sea species (Vinogradov, 1968). In contrast, the warm water species transported by the Tsushima warm current are numerous. For example, Toyama Bay has 69 warm water species and 15 cold water species of copepod fauna (Hirakawa et al., 1990), and Wakasa Bay contains 50 warm water species and seven cold water species of copepod fauna (Iguchi et al., 1999). This pattern also occurs in Ishikari Bay, where we observed 18 warm water species and nine cold water species. Because Ishikari Bay is located in the northern Japan Sea, fewer warm water species are found here than at the two southern locations (Toyama Bay and Wakasa Bay, Fig. 1a). We hypothesise that during summer and autumn, when the strength of the Tsushima warm current is greater, warm water species may have been transported northward, leading to a higher copepod species diversity in Ishikari Bay (Fig. 4b).

Acknowledgements

We wish to express our thanks to the captain and crew of the R/V *Oyashio–Maru* and the staff of the Hokkaido Research Organization of the Central Fisheries Research Institute for their effort in zooplankton sampling and hydrographic data collection. This study was supported by Grant–in–Aid for Scientific Research (A) 24248032 and Grant–in–Aid for Scientific Research on Innovative Areas 24110005 from the Japan Society for the Promotion of Science (JSPS).

Literature cited

Anraku, M. (1953) Seasonal distribution of pelagic copepods at Oshoro Bay, west coast of Hokkaido. *Bull. Fac. Fish. Hokkaido Univ.*, **3**, 187–192.

Asami, H., Shimada, H., Ishida, R. and Takayanagi, S. (2010) Interannual variabilities of a few dominant copepods abundances during spring in Ishikari Bay, western Hokkaido, Japan. *Sci. Rep. Hokkaido Fish. Exp. Stn.*, **77**, 1–11.

Ayata, S.D., Stolba, R., Comtet, T. and Thiebaut, E. (2011) Meroplankton distribution and its relationship to coastal mesoscale hydrological structure in the northern Bay of Biscay (NE Atlantic). *J. Plankton Res.*, **33**, 1193–1211.

Brodeur, R.D., Wilson, M.T. and Ciannelli, L. (2000) Spatial and temporal variability in feeding and condition of age–0 walleye pollock (*Theragra chalcogramma*) in frontal regions of the Bering Sea. *ICES J. Mar. Sci.*, **57**, 256–264.

Brodsky, K.A. (1967) *Calanoida of the Far–Eastern Seas and Polar Basin of the USSR*. Israel Program Scientific Translation, Jerusalem.

Ciannelli, L., Brodeur, R.D. and Napp, J.M. (2004) Foraging impact on zooplankton by age–0 walleye pollock (*Theragra chalcogramma*) around a front in the southeast Bering Sea. *Mar. Biol.*, **144**, 515–526.

Field, J.G., Clarke, K.R. and Warwick, R.M. (1982) A practical strategy for analysing multispecies distribution patterns. *Mar. Ecol. Prog. Ser.*, **8**, 37–52.

Hayashi, K. (1980) Occurrence pattern of commercial fishes and biotic environment in Ishikari Bay, Hokkaido. *Bull. Japan. Soc. Fish. Oceanogr.*, **37**, 19–23.

Highfield, J.M., Eloire, D., Conway, D.V.P., Lindeque, P.K., Attrill, M.J. and Somerfield, P.J. (2010) Seasonal dynamics of meroplankton assemblages at station L4. *J. Plankton Res.*, **32**, 681–691.

Hirakawa, K., Ikeda, T. and Kajihara, N. (1990) Vertical distribution of zooplankton in Toyama Bay, southern Japan Sea, with special reference to Copepoda. *Bull. Plankton Soc. Japan*, **37**, 111–126.

Hirakawa, K. and Imamura, A. (1993) Seasonal abundance and life history of *Metridia pacifica* (Copepoda : Calanoida) in Toyama Bay, southern Japan Sea. *Bull. Plankton Soc. Japan*, **40**, 41–54.

Iguchi, N. and Ikeda, T. (1999) Production, metabolism and *P* : *B* ratio of *Euphausia pacifica* (Crustacea : Euphausiacea) in Toyama Bay, southern Japan Sea. *Plankton Biol. Ecol.*, **46**, 68–74.

Iguchi, N., Wada, Y. and Hirakawa, K. (1999) Seasonal changes in the copepod assemblage as food for larval anchovy in western Wakasa Bay, southern Japan Sea. *Bull. Japan Sea Natl. Fish. Res. Inst.*, **49**, 69–80.

Kendall, A.W. and Nakatani, T. (1992) Comparisons of early-life-history characteristics of walleye pollock *Theragra chalcogramma* in Shelikof Strait, Gulf of Alaska, and Funka Bay, Hokkaido, Japan. *Fish. Bull. U.S.*, **90**, 129-138.

Kotori, M. (1977) Plankton investigations in Ishikari Bay, Hokkaido. Zooplankton biomass during the summer and autumn of 1975. *Sci. Rep. Hokkaido Fish. Exp. Stn.*, **19**, 1-11.

Kotori, M. (1983) Plankton investigations in Ishikari Bay, Hokkaido. VI. Zooplankton biomass in 1980 and 1981. *Sci. Rep. Hokkaido Fish. Exp. Stn.*, **25**, 1-6.

Logerwell, E.A., Duffy-Anderson, J., Wilson, M. and Mckelvey, D. (2010) The influence of pelagic habitat selection and interspecific competition on productivity of juvenile walleye pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*) in the Gulf of Alaska. *Fish. Oceanogr.*, **19**, 262-278.

Minoda, T., Shiga, N. and Kaneko, M. (1979) Feeding habits of juvenile salmon and zooplankton-2. Zooplankton abundance estuarine of Ishikari River during spring. pp. 99-115, *Group Report on Salmon Research 1978*. Hokkaido Natl. Fish. Res. Lab., Yoichi.

Motoda, S. (1957) North Pacific standard plankton net. *Info. Bull. Planktology Japan*, **4**, 13-15.

Motoda, S. (1959) Devices of simple plankton apparatus. *Mem. Fac. Fish. Hokkaido Univ.*, **7**, 73-94.

Motoda, S. (1971) Oshoro Marine Biological Station, Hokkaido University, Japan. *Bull. Plankton Soc. Japan*, **18**, 32-94.

Ohtsuka, S., Ueda, H., Hattori, H., Hirakawa, K., Itoh, H., Iwasaki, N., Nishida, S. and Toda, T. (1997) Copepoda. pp. 649-1004, Chihara, M. and Murano, M. (eds.), *An Illustrated Guide to Marine Plankton in Japan*, Tokai University Press, Tokyo.

Pedersen, T. and Fossheim, M. (2008) Diet of 0-group stages of capelin (*Mallotus villosus*), herring (*Clupea harengus*) and cod (*Gadus morhua*) during spring and summer in the Barents Sea. *Mar. Biol.*, **153**, 1037-1046.

Shannon, C.E. and Weaver, W. (1949) *The Mathematical Theory of Communication*. The University of Illinois Press, Urbana.

Tomita, M., Ikeda, T. and Shiga, N. (1999) Production of *Oikopleura longicauda* (Tunicata : Appendicularia) in Toyama Bay, southern Japan Sea. *J. Plankton Res.*, **21**, 2421-2430.

Tomita, M., Shiga, N. and Ikeda, T. (2003) Seasonal occurrence and vertical distribution of appendicularians in Toyama Bay, southern Japan Sea. *J. Plankton Res*., **25**, 579-589.

Uchima, M. (1979) Morphological observation of developmental stages in *Oithona brevicornis* (Copepoda, Cyclopoida). *Bull. Plankton Soc. Japan*, **26**, 59-76.

Vinogradov, M.E. (1968) *Vertical Distribution of the Oceanic Zooplankton*. Israel Program for Scientific Translations, Jerusalem.

Yamaguchi, A., Ikeda, T. and Shiga, N. (1998) Population structure and life cycle of *Pseudocalanus minutus* and *Pseudocalanus newmani* (Copepoda : Calanoida) in Toyama Bay, southern Japan Sea. *Plankton Biol. Ecol.*, **45**, 183-193.

Yamashita, T., Umebayashi, T., Homma, S. and Yamazaki, S. (2004) Nutrient and water mass changes in Ishikari Bay : Changes in neritic and oceanic water. *Proc. Coast. Engineer. JSCE*, **51**, 1081-1085.

Yoshida, K., Domon, K. and Watanabe, T. (1977) Physical and chemical conditions on the inshore fishing grounds in Ishikari Bay. *J. Hokkaido Fish. Exp. Stn.*, **34**, 1-6.

Zenkevitch, L. (1963) *Biology of the Seas of the U.S.S.R.*, George Allen and Unwin, London.