Polar Biosci., **19**, 133–141, 2006

Scientific note

Unusual abundance of appendicularians in the seasonal ice zone (140°E) of the Southern Ocean

Megumu Tsujimoto[1]*, Kunio T. Takahashi[1], Toru Hirawake[1,2] and Mitsuo Fukuchi[1,2]

[1] *National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
[2] *Department of Polar Science, School of Maltidisciplinary Sciences, The Graduate University for Advanced Studies (SOKENDAI), Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
**Corresponding author. E-mail: tsujimoto@nipr.ac.jp*

(Received August 5, 2005; Accepted September 14, 2005)

Abstract: During the 43rd Japanese Antarctic Research Expedition (JARE) cruise on March 10–12 in 2002, NORPAC net samplings at three stations along a south-north transect, *ca.* 140°E in the Indian sector were conducted to survey zooplankton community structure and abundance in the seasonal ice zone (SIZ) of the Southern Ocean. A total of fourteen species/taxa were identified from the three stations. While copepods were numerically dominant at two stations (79.9% and 93.1% respectively of total abundance), appendicularians were found to be numerically dominant (84.0% of total abundance) at the southernmost station. This dominance of Appendicularia at this station suggested that Appendicularia is possibly an integral part of the community structure of the zooplankton in the SIZ. The Southern Boundary (SB) on the 140°E transect was found to be located at ~64.30°S and the southernmost station was located south of the SB while the two other stations were located north of the SB. Some species, such as *Rhincalanus gigas*, *Calanus simillimus*, Amphipoda, Euphausiacea, and Polychaeta, had distribution patterns that correlated with the position of the SB, therefore the SB is considered important in influencing the distribution of the zooplankton and its community structure in the SIZ.

key words: seasonal ice zone (SIZ), Southern Boundary (SB), Appendicularia, zooplankton, Copepoda

Introduction

The Southern Ocean is characterized by a distinctive series of zones that separate a distinguished zonal oceanographic feature and is divided into major current systems, such as Antarctic Circumpolar Current (ACC) and Coastal Current (CC). The boundaries between the zones are usually circumpolar frontal systems (Orsi *et al.*, 1995). Within these biogeographic zones and between these fronts, the population of biological communities tends to be distinct. Zooplankton communities have a well demonstrated latitudinal gradient in structure and species composition. These suggested changes imply a strong influence by the physical conditions of each zone (Deacon, 1982; Atkinson and Sinclair, 2000; Takahashi *et al.*, 2002). Such zooplankton communities reflect the physical conditions of the biogeographic zones and are recognizable as an important element in detecting the impacts of environmental change on the Southern Ocean ecosystem.

The Antarctic seasonal ice zone (SIZ) is recognized as an ecologically important region in the Southern Ocean (Brierley and Thomas, 2002). Its significance is based on a strong association between community composition and ice formation (Brierley and Thomas, 2002). Sea-ice provides plankton with a suitable place to grow and rest, but reported reductions in the sea-ice extent have clearly been removing this favorable habitat (Loeb *et al*., 1997; Nicol *et al*., 2000; Atkinson *et al*., 2004). Alternately, Antarctic krill, *Euphausia superba*, is widely recognized as a key species in the ecosystem of the Southern Ocean and a krill-centered food web is broadly accepted (Marr, 1962; Hempel, 1985). A study by Nicol (1994), however noted the importance of the entire plankton including salps and copepods and suggested a more complex and unstable food web existed in the Southern Ocean. Thus it is clear additional data on the structure and distribution of the zooplankton community in the Southern Ocean is required to understand the ecosystem of the Southern Ocean.

In addition to the key SIZ groups, such as krill, copepoda, and salpa, appendicularians are known to be one of the important filter feeders which consume small particles in the ocean. Few studies on the distribution of Appendicularia have been previously reported from the Southern Ocean. A recent study by Hunt and Hosie (2005), however, pointed out a significant occurrence of appendicularian in the SIZ in the Southern Ocean. Further investigations on appendicularian are expected to substantiate the character of the zooplankton communities as well as to quantify the role of Appendicuaria in the community structure of the Southern Ocean.

Japanese Antarctic Research Expeditions (JARE) have been conducting zooplankton samplings every austral summer since 1972 in the Indian Ocean sector of the Antarctic Ocean, using a NORPAC standard net (Motoda, 1957). Fukuchi and Tanimura (1981), Watanabe *et al.* (1984) and Takahashi *et al.* (1997) have reported the sampling data. Consequently, initial analyses of total zooplankton biomass have already been reported and some 4–6 years of cyclic variation in abundance and its relationship to physical processes such as sea-ice extent or the Antarctic Circumpolar Wave have been reported (Takahashi *et al*., 1998). In summer 2001/2002, a time-series/multi-ship surveys along the south-north transect on *ca.* 140°E from 66 to 60°S were carried out in the Antarctic Ocean (Odate and Fukuchi, 2003). The present samples were collected on the JARE-43 cruise abroad *Shirase* as a part of the time-series/multi-ship surveys. In this note, we discuss distribution, abundance, and species composition of the zooplankton communities along 140°E as well as the unusual abundance of appendicularian in particular.

Materials and methods

The survey was conducted from March 10 to 12 in 2002 aboard the Japanese icebreaker *Shirase* during the 43th Japanese Antarctic Research Expedition (JARE) cruise. Zooplankton were collected at three stations along the south-north transect on *ca.* 140°E from 66 to 61°S (Fig. 1, Table 1), using a NORPAC net (mouth diameter

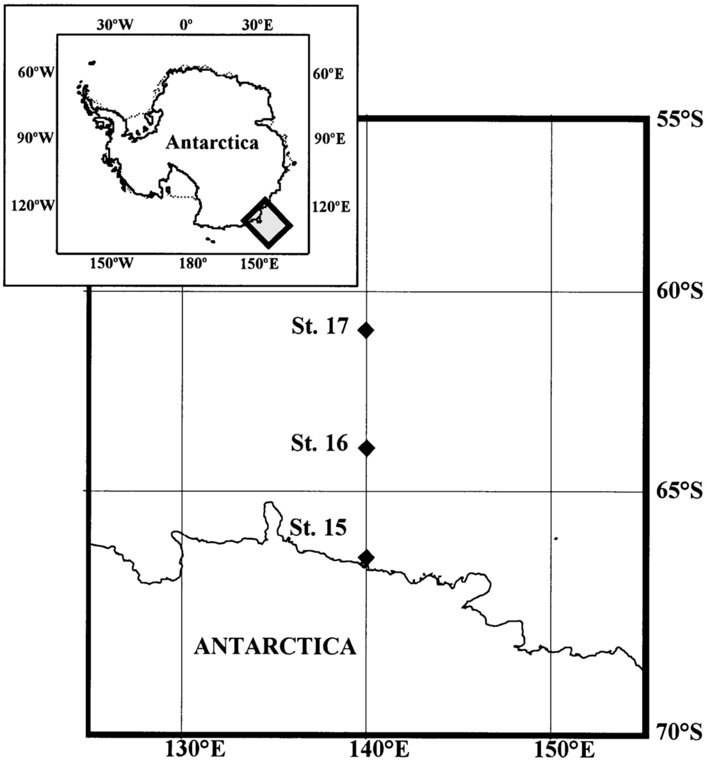

Fig. 1. Sampling stations abroad the icebreaker *Shirase* in March 2002.

Table 1. Sampling information and chlorophyll *a* concentration (0–150 m) at 3 stations in JARE-43.

Station	Date	Time (LT)	Location		Sampling depth (m)	Vol. of water filtered (m^3)	Chlorophyll *a* ($mg\ m^{-2}$)
			Latitude (S)	Longitude (E)			
15	Mar. 10	08:42	66° 28.0′	140° 00.7′	0-150	24.10	299.87
16	Mar. 11	08:50	63° 59.2′	140° 01.6′	0-150	50.09	20.09
17	Mar. 12	08:45	61° 02.0′	139° 58.3′	0-150	41.92	14.19

0.45 m, side length 1.8 m, nylon mesh size 330 μm (Motoda, 1957)). The net was equipped with a flow meter to estimate the volume of water filtered, and was vertically hauled from approximately 150 m depth to the surface at a speed of *ca.* 1 m per second. Soon after collection, samples from Stations 16 and 17 were preserved in a buffered 5% formaldehyde and seawater solution. The sample from Station 15 was preserved in a buffered 10% formaldehyde and seawater solution due to the large amount of phytoplankton cells entangled in the sample.

Zooplankton were identified to lowest possible taxa and counted. These included Amphipoda, Appendicularia, Chaetognatha, Copepoda, Copepoda nauplii, Decapoda, Euphasiid, Foraminifera, Gastropoda, *Limacina* spp., Ostracoda, Polychaeta, and

Table 2. Zooplankton compositions at each station. Euphausiacea-C indicates clyptopis larvae stage while Euphausiacea-F indicates furcilic larvae stage.

Category	Station 15			Station 16			Station 17		
	individuals	ind m^{-3}	%	individuals	ind m^{-3}	%	individuals	ind m^{-3}	%
Amphipoda	–	–	–	8	0.16	0.19	4	0.10	0.13
Appendicularia	7884	327.14	84.03	28	0.56	0.65	65	1.55	2.04
Chaetognatha	3	0.12	0.03	117	2.34	2.72	38	0.91	1.19
Copepoda	1406	58.34	14.99	3433	68.54	79.91	2964	70.71	93.15
Copepoda nauplii	43	1.78	0.46	17	0.34	0.40	39	0.93	1.23
Decapoda	–	–	–	1	0.02	0.02	–	–	–
Euphausiacea-C	–	–	–	286	5.71	6.66	23	0.55	0.72
Euphausiacea-F	–	–	–	87	1.74	2.03	46	1.10	1.45
Foraminifera	4	0.17	0.04	66	1.32	1.54	3	0.07	0.09
Gastropoda	2	0.08	0.02	56	1.12	1.30	–	–	–
Limacina spp.	16	0.66	0.17	184	3.67	4.28	–	–	–
Ostracoda	–	–	–	12	0.24	0.28	–	–	–
Polychaeta	24	1.00	0.26	–	–	–	–	–	–
Vibilia sp.	–	–	–	1	0.02	0.02	–	–	–
Total	9382	389.29	100.00	4296	85.77	100.00	3182	75.91	100.00

Vibilia sp. (see Table 2). Euphausiid larvae were further identified to calyptopis and furcilic stages while Copepoda were identified to copepodite and nauplius stages too. Within the copepodite samples, *Rhincalanus gigas*, *Calanoides acutus*, *Calanus propinquus*, and *Calanus simillimus* were identified and counted as these large biomass-dominant species have been well studied (Kawamura, 1986; Atkinson, 1998; Atkinson and Sinclair, 2000). *Vibilia* sp. were clearly identified within Amphipoda and were thus sorted separately from Amphipoda. Counts were converted into the number of individuals per 1 m^3 for each station.

Along the south-north transect the oceanographic conditions were recorded by the CTD (Falmouth Scientific Inc. TRITON ICTD) and XCTD casts (Kinoshita and Nosaka, 2005). A total of 3 CTD casts and 20 XCTD casts were taken and these data were used to estimate the vertical profiles of the water temperature and salinity. While the CTD data were obtained to the sea floor, only the information on the upper 1000 m of the water column was applied in the study.

Results and discussion

There was quite a wide range of maximum and minimum temperatures at each station in the vertical profile from 200 m depth to the surface (where the samples were hauled). The maximum temperatures were all obtained at 200 m depth and these increased from St.15 to St.17 (0.13°C, 1.65°C, 2.06°C in sequence). Likewise, the minimum temperatures detected at approximately 100 m depth increased from the south to the north (−1.6°C, −0.24°C, 0.28°C in turn) (Fig. 2). Chlorophyll *a* concentration increased slightly from 17.14 mg Chl *a* m^{-2} at Station 17 to 20.09 mg Chl *a* m^{-2} at Station 15 (Table 1), but then changed dramatically by an order of magnitude at the southern Station 15 (299.87 mg Chl *a* m^{-2}).

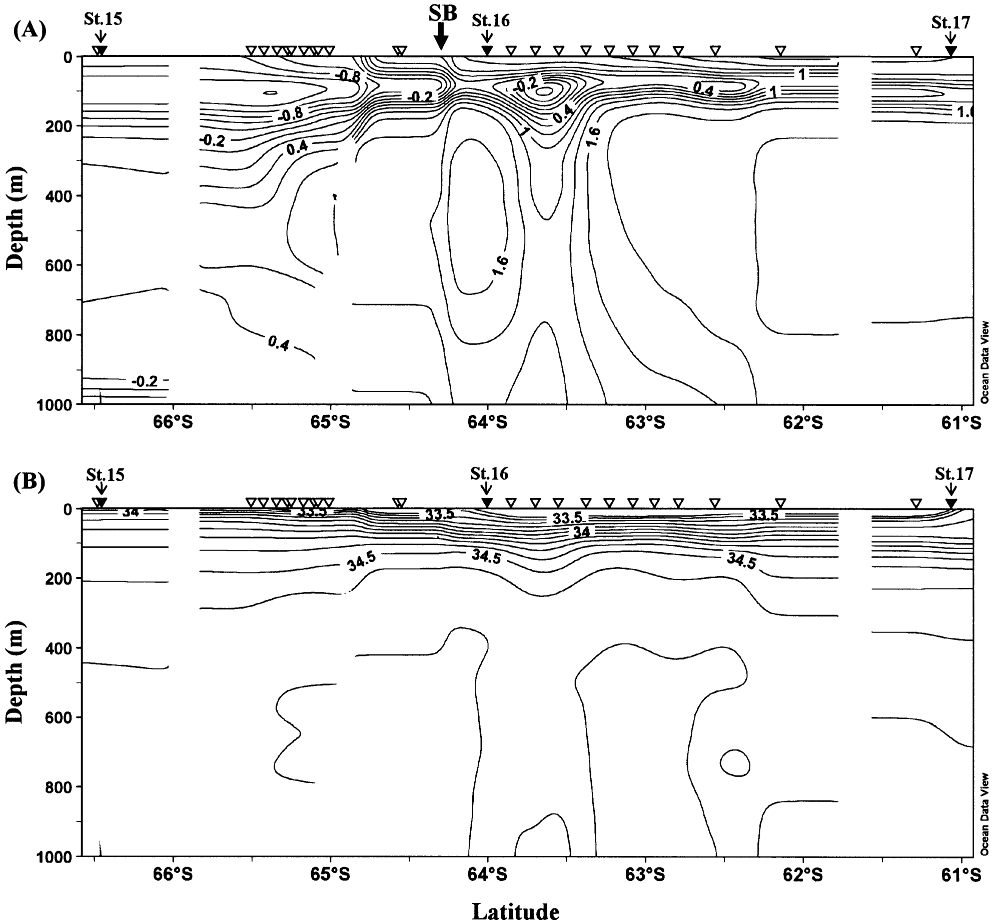

Fig. 2. Vertical profiles of temperature (A) and salinity (B) through 1000 m along 140°E between 66.5° and 61°S. The numbers on top of each ▼ indicate the corresponding stations where NORPAC net hauls were conducted, and the symbol ▽ along the top of each figure indicates CTD stations. The location of the Southern Boundary (SB) is indicated. Areas exceeding the maximum analyzing capability of the program due to the limited numbers of applicable CTD casts obtained show blank profiles in the figures.

In the Antarctic Ocean, there are two major current systems; the Antarctic Circumpolar Current (ACC) and the Coastal Current (CC). Additional circumpolar frontal systems further sub-divide the major currents (Deacon, 1982; Orsi *et al.*, 1995). The Southern Boundary (SB) is one of these circumpolar frontal systems of ACC and represents the poleward limit of the circumpolar circulation, which corresponds to the poleward limit of the oxygen minimum associated with the Upper Circumpolar Deep Water. Sokolov and Rintoul (2002) found this feature to coincide with the southern limit of maximum potential temperature (θ_{max}) water warmer than 1.5°C along 140°E (Fig. 2). In this study, the SB was found to be located at ~64.30°S. Therefore Station 15 was located south of SB while Station 16 and Station 17 were located north of SB.

A total of fourteen species/taxa were classified from the three stations (Table 2). The zooplankton composition at Station 16 was found to be the most diverse in terms of numbers of species/taxa present, with thirteen species/taxa out of the fourteen present. The total number of individuals per m^3 was the largest at Station 15 (389.3 ind m^{-3}), followed by Station 16 (85.8 ind m^{-3}), and Station 17 (75.9 ind m^{-3}). At Station 15 appendicularians were numerically dominant (327.1 ind m^{-3}), contributing to 84.0% of total zooplankton abundance at the station. At Stations 16 and 17 copepods were numerically dominant, accounting for 79.9% and 93.1% respectively of total zooplankton abundance at each station (Table 2).

The copepoda dominance of the zooplankton communities found at two stations is consistent with the findings from previous studies on the zooplankton community structure in the Indian sector of the Antarctic Ocean (Kawamura, 1987; Yamada *et al*., 1991, 1992; Hosie *et al*., 1997; Chiba *et al*., 2001). However, the high abundance of Appendicularia, which is far larger than that of copepoda, has only previously been reported once before in surveys of the zooplankton communities in the Seasonal Ice Zone (SIZ). Although Appendicularia has been previously reported, in the relatively colder waters, such as in southern ACC (Yamada and Kawamura, 1986; Chiba *et al*., 2001), this much greater abundance of Appendicularia has not been reported until the recent study of Hunt and Hosie (2005). They conducted a Continuous Plankton Recorder (CPR) survey of the same region (along 140°E) two weeks prior to this study and also reported the dominance of Appendicularia in the zooplankton community south of the SB (192.9 ind m^{-3}). Based on data presented above and our data, it is likely that further studies on the distribution of Appendicularia in SIZ will substantiate the character of these zooplankton communities in the Indian sector of the Antarctic Ocean, and quantify the role Appendicularia may play in the community structure of the ecosystem of the Southern Ocean.

Percentage abundance contributions without Appendicuralia are similar at all stations (Fig. 3). However, total abundance (ind m^{-3}) at each station was relatively low compared to those of previous studies in the Indian Ocean sector, although they fall into the range of abundances of zooplankton previously reported from the same region (Chiba *et al*., 2001). Copepoda was the dominant taxon of the zooplankton community at the all stations, contributing more than 80% of the abundance. Of the four large, biomass-dominating species of copepoda, *Calanoides acutus* was the most dominant among other species at all stations (Fig. 4). While *C. acutus* and *Calanus propinquus* occurred at all stations, their abundance appeared relatively low compared to those of previous studies (Yamada *et al*., 1991, 1992; Chiba *et al*., 2001). This can largely be explained by the differences in the sampling times. Later sampling, which occurred at the end of the austral summer in this study probably resulted in the migration to great depth for overwintering of *C. acutus* and *C. propinquus.* However, *Rhincalanus gigas* and *Calanus simillimus*, species which prefer warm water, were observed at Station 16 and Station 17, north of the SB.

The SB is associated with steep physical gradients in the SIZ and some species of zooplankton show a strong correlation with this frontal system (Schnack-Schiel *et al*., 1995). In this study as well, the distribution of some species other than copepods also showed a correlation with the SB. Amphipoda and Euphausiacea (in larvae stages) were

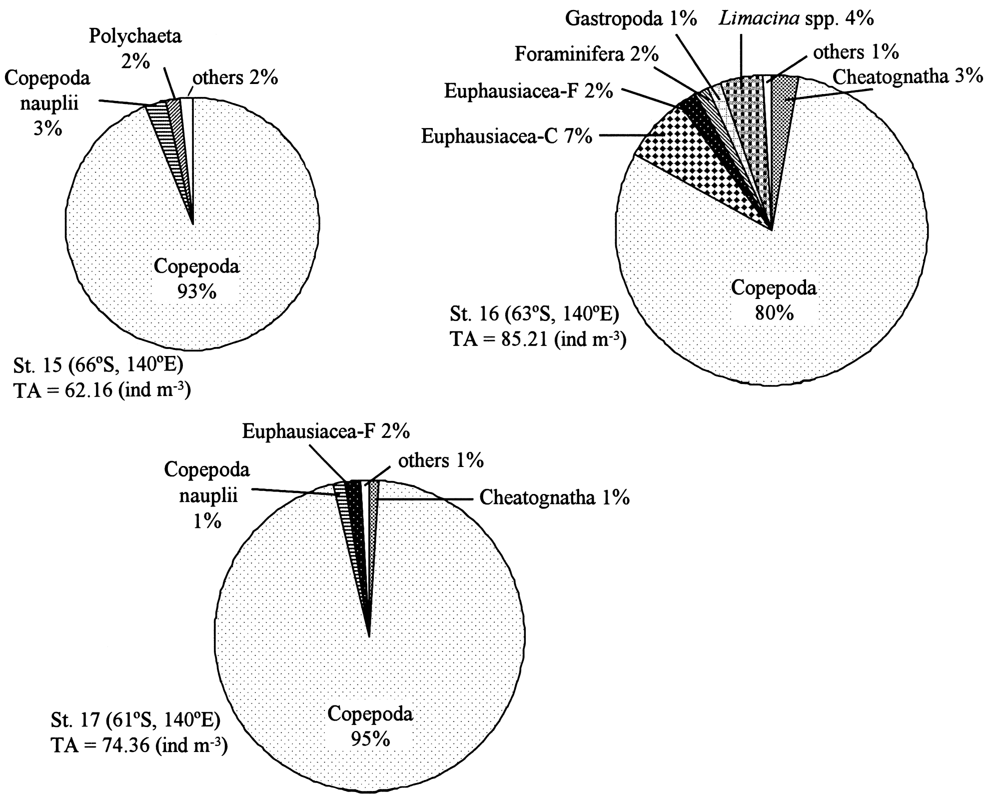

Fig. 3. Major dominant zooplankton taxa recorded on each station. TA: total abundance.

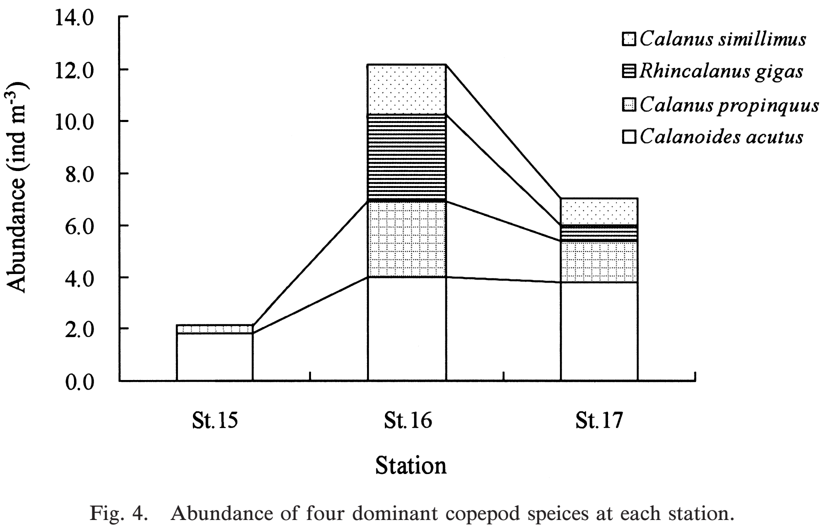

Fig. 4. Abundance of four dominant copepod speices at each station.

present at both stations north of the SB but did not appear to the south. Conversely, Polychaeta appeared at the station south of the SB, but did not appear at two stations north of the SB. Hence this study also suggests that the SB plays a major role in influencing the distribution of zooplankton and thus the community structure in the SIZ.

Acknowledgments

This zooplankton survey was one part of the results of the time-series/multi-ship research program conducted under the JARE-STAGE (Studies on Antarctic ocean and Global Environment) project, and the present study was partly supported by the Grant-in-aid for Scientific Research (S) (Grant#: 16101001). We would like to thank officers and crew of the icebreaker *Shirase* and expedition members of JARE-43 for collecting data and zooplankton samples.

References

Atkinson, A. (1998): Life cycle strategies of epipelagic copepods in the Southern Ocean. J. Mar. Syst., **15**, 289–311.

Atkinson, A. and Sinclair, J.D. (2000): Zonal distribution and seasonal vertical migration of copepod assemblages in the Scotia Sea. Polar Biol., **23**, 46–58.

Atkinson, A., Siegel, V., Pakhomov, E. and Rothery, P. (2004): Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature, **432**, 100–103.

Brierley, A.S. and Thomas, D.N. (2002): Ecology of Southern Ocean pack ice. Advances in Marine Biology Vol. 43, ed. by A.J. Southward *et al.* London, Academic Press, 171–276.

Chiba, S., Ishimaru, T., Hosie, G.W. and Fukuchi, M. (2001): Spatio-temporal variability of zooplankton community structure off east Antarctica (90 to 160°E). Mar. Ecol. Prog. Ser., **216**, 95–108.

Deacon, G.E.R. (1982): Physical and biological zonation of the Southern Ocean. Deep-Sea Res., **29**, 1–15.

Fukuchi, M. and Tanimura, A. (1981): Plankton samplings on board Fuji in 1972–1980. JARE Data Rep., **60** (Mar Biol. 1), 27 p.

Hempel, G. (1985): Antarctic marine food web. Antarctic Nutrient Cycles and Food Webs, ed. by W.R. Siegfried *et al.* Berlin, Springer, 266–270.

Hosie, G.W., Cochran, T.G., Pauly, T., Beaumont, K.L., Wright, S.W. and Kitchener, J.A. (1997): Zooplankton community structure of Prydz Bay, Antarctica, January–February 1993. Proc. NIPR Symp. Polar Biol., **10**, 90–133.

Hunt, B.P.V. and Hosie, G.W. (2005): Zonal structure of zooplankton communities in the Southern Ocean south of Australia: results from a 2150 km continuous plankton recorder transect. Deep-Sea Res., Part I, **52**, 1241–1271.

Kawamura, A. (1986): Has marine Antarctic ecosystem changed?—A tentative comparison of present and past macrozooplankton abundances. Mem. Natl Inst. Polar Res., Spec. Issue, **40**, 197–211.

Kawamura, A. (1987): Two series of macrozooplankton catches with the N70V net in the Indian sector of the Antarctic Ocean. Proc. NIPR Symp. Polar Biol., **1**, 84–89.

Kinoshita, H. and Nosaka, T. (2005): Oceanographic data of the 43rd Japanese Antarctic Research Expedition from December 2001 to March 2002. JARE Data Rep., **282** (Oceanography 27), 63 p.

Loeb, V., Siegel, V., Holm-Hansen, O., Hewitt, R., Fraser, W., Trivelpiece, W. and Trivelpiece, S. (1997): Effects of sea-ice extent and krill or salp dominance on the Antarctic food web. Nature, **38**, 897–900.

Marr, J.W.S. (1962): The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). Discovery Rep., **32**, 33–464.

Motoda, S. (1957): North Pacific standard net. Inf. Bull. Planktology Jpn., **4**, 13–15.

Nicol, S. (1994): Antarctic krill—changing perceptions of its role in the Antarctic ecosystem. Antarctic Science: Global Concerns, ed. by G. Hempel. Berlin, Springer, 145–166.

Nicol, S., Pauly, T., Bindoff, N.L., Wright, S., Thiele, D., Hosie, G.W., Strutton, P.G. and Woehler, E. (2000): Ocean circulation of east Antarctica affects ecosystem structure and sea-ice extent. Nature, **406**, 504–507.

Odate, T. and Fukuchi, M. (2003): Report on Workshop "Data management and synthesis of the results obtained during multi-ship/time-series study in 2001/2002 austral summer". Nankyoku Shiryô (Antarct. Rec.), **47**, 94–100 (in Japanese with English abstract).

Orsi, A.H., Whitworth, T., III and Norwlin, W.D., Jr. (1995): On the meridional extent and fronts of the Antarctic Circumpolar Current. Deep-Sea Res., **42**, 641–673.

Schnack-Schiel, S.B., Thomas, D., Dieckmann, G.S., Eicken, H., Gradinger, R., Spindler, M., Weissenberger, J., Mizdalski, E. and Beyen, K. (1995): Life cycle strategy of the Antarctic copepod *Stephos longipes.* Prog. Oceanogr., **36**, 45–75.

Sokolov, S. and Rintoul, S.R. (2002): Structure of Southern Ocean fronts at 140°E. J. Mar. Syst., **37**, 151–184.

Takahashi, K., Tanimura, A. and Fukuchi, M. (1997): Plankton sampling on board Shirase in 1983–1996—NORPAC standard net samples—. JARE Data Rep., **224** (Mar. Biol. 28), 35 p.

Takahashi, K., Tanimura, A. and Fukuchi, M. (1998): Long-term observation of zooplankton biomass in the Indian Ocean sector of the Southern Ocean. Mem. Natl Inst. Polar Res., Spec. Issue, **52**, 209–219.

Takahashi, K.T., Kawaguchi, S., Kobayashi, M., Hosie, G.W., Fukuchi, M. and Toda, T. (2002): Zooplankton distribution patterns in relation to the Antarctic Polar Front Zones recorded by Continuous Plankton Recorder (CPR) during 1999/2000 *Kaiyo Maru* cruise. Polar Biosci., **15**, 97–107.

Watanabe, K., Nakajima, Y., Ino, Y., Sasaki, H. and Fukuchi, M. (1984): Plankton samplings on board *Fuji* in 1980–1983. JARE Data Rep., **90** (Mar. Biol. 5), 11 p.

Yamada, S. and Kawamura, A. (1986): Some characteristics of the zooplankton distribution in the Prydz Bay region of the Indian sector of the Antarctic Ocean in the summer of 1983/84. Mem. Natl Inst. Polar Res., Spec. Issue, **44**, 86–95.

Yamada, S., Tanimura, A. and Minoda, T. (1991): Copepods collected along 13°E longitude of the Antarctic Ocean in the 1973 summer. Nankyoku Shiryô (Antarct. Rec.), **35**, 155–160.

Yamada, S., Tanimura, A. and Minoda, T. (1992): Copepods collected along 33.5°E longitude of the Antarctic Ocean in the 1976 summer. Nankyoku Shiryô (Antarct. Rec.), **36**, 60–64.