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Scientific note

Distribution of Copepoda along 140°E in the Indian sector of the Southern Ocean

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Abstract: NORPAC net samplings at three stations along a south-north transect on *ca*. 140°E were conducted in the Indian sector of the Southern Ocean from March 10 to 12 in 2002 during the 43rd Japanese Antarctic Research Expedition. The survey was held to examine the community structure and abundance of Copepoda in the seasonal ice zone of the Southern Ocean. A total of 15 species of copepod were identified at the stations. For nine species of copepod, *Microcalanus pygmaeus*, *Calanus simillimus*, *Rhincalanus gigas*, *Euchaeta antarctica*, *Clausocalanus laticeps*, *Scolecithricella minor*, *Metridia lucens*, *Haloptilus oxycephalus* and *Oithona frigida,* disparities of the distributions between the south of the Southern Boundary (SB) and the north became apparent. As here was a distinct difference of, about 2°C, in the sea surface temperature between the south and north of the SB, these disparities were considered to be influenced by the difference in the physical structure in the ocean, in particular by the water temperature, which was driven by the SB. Among *Calanoides acutus*, *Calanus propinquus*, and *R. gigas*, the earlier copepodite stages were observed at higher latitudes at all stations. This trend was considered to be a result of the sea ice retreat, which caused a later spawning period for Copepoda. In addition, an interaction between the sea ice conditions and the community structure of copepod along 140°E was suggested.

key words: Copepoda, sea ice retreat, seasonal ice zone, Southern Boundary (SB), zooplankton

Introduction

The Antarctic seasonal ice zone is acknowledged as a region of ecological significance in the Southern Ocean, based on the strong interaction between community composition and ice formation in the area (Brierley and Thomas, 2002). Sea-ice provides an important habitat for plankton, however, there has been a reduction in the extent of sea-ice, which in turn has led to a reduction of this critical habitat (Nicol *et al*., 2000; Atkinson *et al*., 2004). Ice edge dynamics are a significant influence on the primary production in polar regions (Brierley and Thomas, 2002), and the annual advance and retreat of sea ice is thought to control food availability for zooplankton in the Southern Ocean. Furthermore, sea ice conditions are likely to influence the distribution, abundance, and spawning period of copepods (Atkinson *et al*., 1997; Burghart *et al*., 1999; Takahashi, 2003).

The Southern Ocean has a series of biogeographic zones, which are defined by the circumpolar frontal structure (Deacon, 1982; Orsi *et al*., 1995). The physical conditions of these biogeographic zones effects the distribution of zooplankton communities (Deacon, 1982; Atkinson and Sinclair, 2000; Takahashi *et al*., 2002; Hunt and Hosie, 2005, 2006). Japanese Antarctic Research Expeditions (JARE) have been operating NORPAC standard net sampling for zooplankton in the Indian Ocean sector of the Southern Ocean every austral summer since 1972 and data relating to the distribution, abundance, and species composition of copepods have been collected (Yamada *et al*., 1991, 1992; Takahashi *et al*., 1998; Chiba *et al*., 2001, 2002). A JARE time-series/multi-ship survey along one south-north transect on *ca*. 140°E was conducted between November 2001 and March 2002 (Odate and Fukuchi, 2003). NORPAC samples were collected intensively along the 140°E transect for the first time. The area of sampling along 140°E has a relatively narrow marginal ice zone and so is less affected by the presence of sea ice than many other Antarctic regions (Nicol *et al*., 2000). Distinctive characteristics of the Southern Boundary (SB), one of the circumpolar frontal systems of the Antarctic Circumpolar Current (Sokolov and Rintoul, 2002), are thought to influence the distribution and structure of the zooplankton community along 140°E (Tsujimoto *et al*., 2006). In this study, the distribution of copepods, which account for most of the zooplankton community along the surveyed transect, is discussed in relation to the oceanographic fronts of the Southern Ocean as well as to the retreat of sea ice in the area.

Materials and methods

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

Copepods were identified to a species level and individual numbers were counted. *Rhincalanus gigas*, *Calanoides acutus*, *Calanus propinquus*, which are dominant in the Southern Ocean (Smith and Schnack-Schiel, 1990; Atkinson, 1998), were identified to the copepodite stage. Counts were converted into the number of individuals per 1 m^3 for each station.

The sea-ice concentration data were obtained from the National Snow and Ice Data Center (Comiso, 1990, updated 2003), and the position of the ice edge along 140°E was determined as the most northern latitude where the concentration of the sea-ice was above 15% (Hirawake *et al*., 2005).

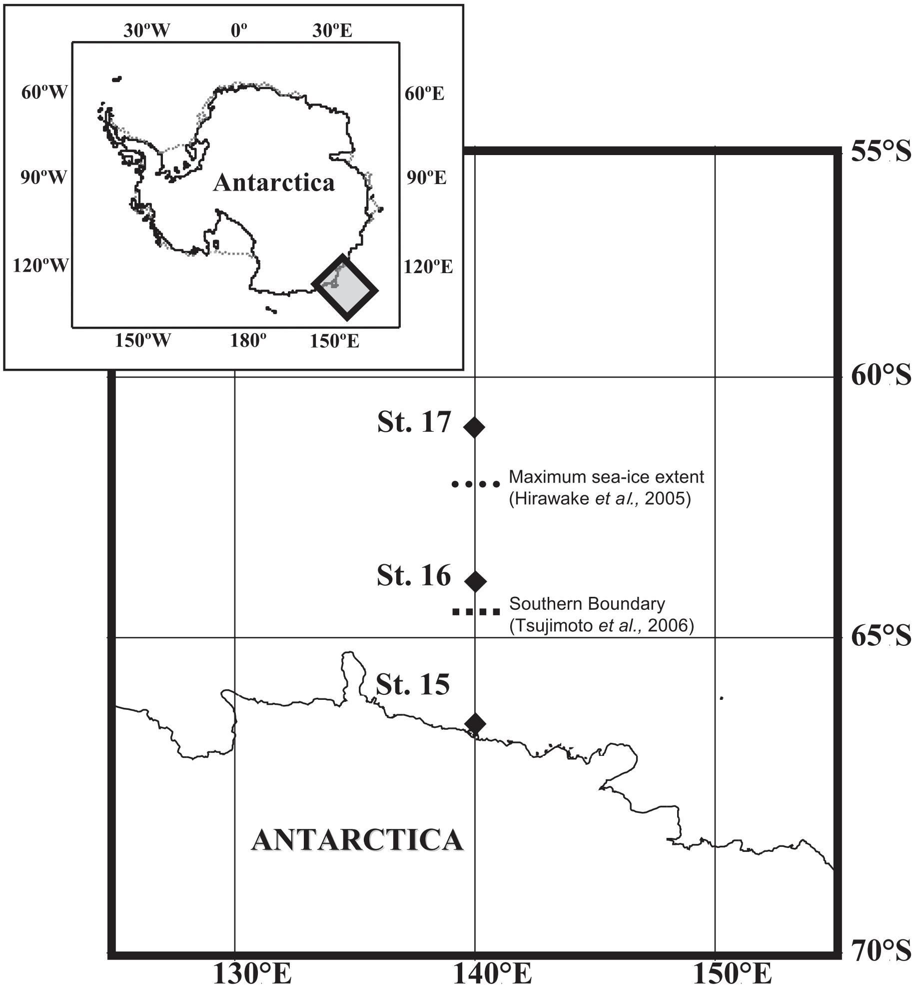

Fig. 1. Sampling stations abroad the icebreaker *Shirase* in March 2002. The positions of the Maximum sea-ice extent (Hirawake *et al.*, 2005) and the Southern Boundary (Tsujimoto *et al.*, 2006) are indicated.

Results and discussion

Together with krill and salps, Copepoda comprise the largest proportion of the zooplankton community in the Indian sector of the Southern Ocean (Kawamura 1987; Yamada *et al.*, 1991, 1992; Hosie *et al.*, 1997; Chiba *et al.*, 2001). The dominance of copepods has previously been reported in the studied area together with an unusual abundance of Appeendicularia (Tsujimoto *et al.*, 2006). A total of 15 species of copepod were identified (Table 1). Six species, *Calanus propinquus*, *Calanoides acutus*, *Ctenocalanus citer*, *Metridia gerlachei*, *Oithona similis*, and *Oncaea antarctica*, were observed at all

Table 1. Copepod species compositions at each station.

Species	Station 15 (66.28°S)			Station 16 (63.59°S)			Station 17 (61.02°S)		
	total	ind m^{-3}	%	total	ind m^{-3}	%	total	ind m^{-3}	%
Calanus propinquus	8	0.3	0.6	148	3.0	4.3	87	2.1	2.9
Calanus simillimus	-	-	-	95	1.9	2.8	45	1.1	1.5
Calanoides acutus	44	1.8	3.1	199	4.0	5.8	216	5.2	7.3
Rhincalanus gigas	-	-	-	166	3.3	4.8	25	0.6	0.8
Euchaeta antarctica	-	-	-	9	0.2	0.3	3	0.1	0.1
Clausocalanus laticeps	-	-	-	221	4.4	6.4	66	1.6	2.2
Ctenocalanus citer	378	15.7	26.9	1162	23.2	33.8	839	20.0	28.3
Scolecithricella minor	-	-	-	87	1.7	2.5	15	0.4	0.5
Metridia gerlachei	8	0.3	0.6	52	1.0	1.5	88	2.1	3.0
Metridia lucens	-	-	-	221	4.4	6.4	810	19.3	27.3
Microcalanus pygmaeus	6	0.2	0.4	-	-	-	-	-	-
Haloptilus oxycephalus	-	-	-	3	0.1	0.1	-	-	-
Oithona frigida	-	-	-	-	-	-	27	0.6	0.9
Oithona similis	864	35.9	61.5	625	12.5	18.2	721	17.2	24.3
Oncaea antarctica	98	4.1	7.0	445	8.9	13.0	22	0.5	0.7
total	1406	58.3	100.0	3433	68.5	100.0	2964	70.7	100.0

three stations (Table 1). *C. citer* alone accounted for more than 25% of the total number of copepod individuals at each station. After *C. citer* the next most abundant taxa was *O. similis*, which comprised 61.5% of the total abundance of copepods at Station 15 (Table 1). These findings reflect a similar pattern of copepod abundance to that determined in surveys conducted along the 13°E and 33.5°E transect from 50°S in 1973 and 1976, respectively (Yamada *et al.*, 1991, 1992).

Two major current systems, the Antarctic Circumpolar Current (ACC) and the Coastal Current, and circumpolar frontal systems characterize the physical and biological features of the Southern Ocean (Deacon, 1982; Orsi *et al.*, 1995). The Southern Boundary (SB), one of these circumpolar frontal systems of the ACC, is associated with steep physical gradients in the seasonal ice zone. The SB is defined as the southern limit of the oxygen minimum in relation to the Upper Circumpolar Deep Water (Sokolov and Rintoul, 2002). In this study the SB was assumed to be located at approximately 64.3°S (Fig. 1, Tsujimoto *et al.*, 2006). Differences in the zooplankton community composition south and north of the SB are clear (Tsujimoto *et al.*, 2006). Station 15, south of SB, had the least number of taxa with only seven species (Table 1). About twice as many copepod species, 13, were found at Stations 16 and 17, which were north of the SB (Table 1). *Microcalanus pygmaeus* was found only at Station 15; whereas eight species, *Calanus simillimus*, *Rhincalanus gigas*, *Euchaeta antarctica*, *Clausocalanus laticeps*, *Scolecithricella minor*, *Metridia lucens*, *Haloptilus oxycephalus* and *Oithona frigida*, were only found north of the SB. Some species of copepod have been shown to be strongly correlated with the SB (Schnack-Schiel *et al.*, 1995; Hunt and Hosie, 2005, 2006). The results of this study confirmed again the significance of the SB as a critical factor affecting the dis-

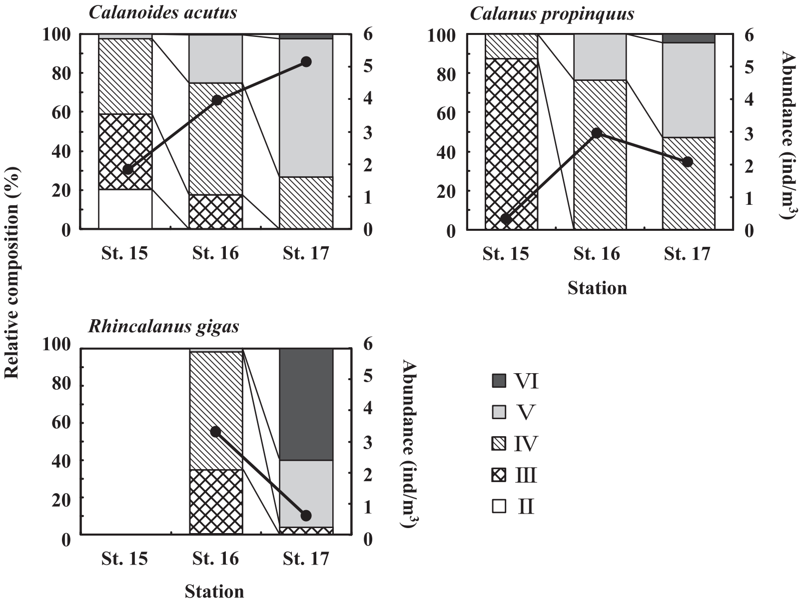

Fig. 2. Relative copepodite stage composition and abundance of the three dominant copepod species at each station.

tribution of copepods in the Southern Ocean. For instance, the physical characteristics associated with the SB possibly influenced the distribution of copepods. There was about a 2°C difference in the surface sea water temperature between Station 15 and Station 16 (St. 15: −0.3°C, St. 16: 2.3°C). The preference of *R. gigas* for relatively warm water has previously been reported (Atkinson, 1991; Bathmann *et al.*, 1993). The difference in water temperature in this study may have restricted *R. gigas* to the relatively warmer water north of the SB. Therefore, the variations in the physical oceanographic structure, such as sea water temperature, driven by the SB may have influenced the distribution and the community structure of zooplankton, in this study, specifically the copepods.

C. acutus was the most abundant of the species of copepod at all stations (Fig. 2). The copepodite I stage was not observed but copepodite stages III to V occurred in all three species. Three species of copepod have been reported to have time differences in their spawning season; beginning with *C. acutus*, *C. propinquus*, and then *R. gigas* (Voronina, 1970, 1978), though no such trend was found in this study. However, the higher the latitude, the earlier the copepodite stages were observed in the three dominant species (Fig. 2). It has been previously reported that the later retreat of the ice edge at higher latitude causes a significant delay in both spawning period and growth (Atkinson *et al.*, 1997; Burghart *et al.*, 1999; Takahashi, 2003). The northern maximum sea ice extent, observed by satellite remote sensing, occurred at approximately 62°S in the area studied (Hirawake *et al.*, 2005). Station 17, located north of 62°S, was thus not influenced by the presence of sea ice. When "Open water" is defined as a sea ice density of less than 15% (Hirawake *et al.*, 2005), the period of open water at Station 16 was five and half months while at Station 15 it was only two months. Consequently, it is possible that the major difference in the timing of sea ice retreat was responsible for the time lag in the spawning period of the copepods, and subsequently in the stage structure of the copepod community.

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