—研究論文—
Scientific Paper

Distribution pattern of macrozooplankton along the 140°E meridian in the Southern Ocean during austral summer 2002 and 2003.

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2002年及び2003年夏季，南極海の東経140度線に沿った大型動物プランクトンの分布パターン

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要旨:　2002年及び2003年の南極海の夏季，東部インド洋区のウイルクスランド沖の東経140度線上において，白鳳丸及びタンガロアによる3回の調査航海によって行われたRMT-8（目合: 4.5 mm，開口面積: 8 m^3）ネット採集によって得られた標本に基づいて，大型動物プランクトン群集構造を調べた．クラスター解析の結果，大型動物プランクトン群集は，南極周極流の南縁（SB-ACC: Southern Boundary of the Antarctic Circumpolar Current）で大きく二つの群集に分けられた．すなわち，SB-ACCの北方では大型動物プランクトン群集は，*Salpa thompsoni, Euphausia frigida* 及び *Themisto gaudichaudii* などのoceanic communityが卓越していた．一方，SB-ACCの南方では *Euphausia superba* 及び *Euphausia crystallorophias* など大陸寄りに主分布域をもつ動物プランクトンが卓越していた．SB-ACCは，南極海の上記の主要な大型動物プランクトン種の出現の差によって特徴付けられることが示唆された．

Abstract:　Field surveys were conducted along 140°E in the Southern Ocean north of Terre Adélie during three cruises: the KH cruise by RV *Hakuho Maru*, and TC1 and TC2 cruises by RV *Tangaroa* during the austral summers of 2002 and 2003.　Macrozooplankton were sampled using a Rectangular Midwater Trawl (RMT 8: mesh size: 4.5 mm; effective mouth area: 8 m^2) along each transect.　Macrozooplankton communities were separated by the Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) based on cluster analysis.　North of the SB-ACC, macrozooplankton assemblages comprised species of the northern oceanic community characterized by *Salpa thompsoni, Euphausia frigida and Themisto gaudichaudii,* while south of the SB-ACC,

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macrozooplankton assemblages were numerically dominated by *Euphausia superba* and/or *Euphausia crystallorophias*. It is suggested that the SB-ACC functions as the major biogeographic barrier to separate the macrozooplankton communities, and the contributions of macro- and meso-zooplankton to total zooplankton abundance varies seasonally as well as regionally in the Indian sector of the Southern Ocean crossing the SB-ACC.

1. Introduction

The Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) is the major oceanographic boundary that divides two current systems: the eastward flowing Antarctic Circumpolar Current (ACC) and the westward flowing Coastal Current (CC) (Orsi *et al*. 1995; Belkin and Gordon 1996; Rintoul *et al*., 1997; Rintoul and Bullister, 1999; Sokolov and Rintoul 2002; Aoki *et al*. 2006). The SB-ACC is also recognized as one of the major biogeographic barriers to the macro scale distribution of zooplankton (Tynan 1998; Nicol *et al*. 2000). Intensive studies on the macrozooplankton community structure and their spatio-temporal variation have been conducted around the Prydz Bay region (60°–80°E), located in the center of the Indian Ocean sector by Hosie and co-workers (Hosie 1994; Hosie and Cochran 1994; Hosie *et al*. 1997). In eastern Antarctica (east of 80°E), however, information on community structure of macrozooplankton is still limited (Hosie *et al*. 2000; Chiba *et al*. 2000, 2001).

As a part of the Japanese Antarctic science project, "Studies on the Antarctic Ocean and Global Environment" (STAGE), a macrozooplankton survey was conducted during three cruises along 140°E, south of Australia, in the austral summers of 2002 and 2003. Here we describe the specific characteristics of the macrozooplankton community structure and their distribution patterns between two masses, north and south of the SB-ACC. Basic information on the macrozooplankton community structure obtained by the present study will provide insight into functioning of the pelagic ecosystem off the eastern Antarctica.

2. Materials and Methods

Field surveys were conducted along 140°E in the Southern Ocean north of Terre Adélie during three cruises: the KH *Hakuho Maru* cruise, and TC1 and TC2 cruises by RV *Tangaroa* (NIWA, New Zealand) (Fig. 1). The KH cruise took place in waters between 61°S and 65°S in early summer during 8 to 14 January in 2002 (KH: January 2002). The TC1 cruise was conducted in mid-summer during the period from 13 to 27 February in 2002 in a wide area from the waters between 60°S and 66°S (TC1: February 2002). The TC2 cruise was carried out in waters between 61°S and 65.5°S in late summer during 26 February to 6 March 2003 (TC2: February–March 2003).

Along the transects, five, eight and six net sampling stations were occupied for the KH, TC1 and TC2 cruises, respectively. One Macrozooplankton sampling was conducted at each station using a Rectangular Midwater Trawl (RMT 8: mesh size: 4.5 mm; effective mouth area: 8 m^2, Baker *et al*. 1973), equipped with a flow meter and a real time depth sensor. The net was towed obliquely from the surface to 200 m at 2 to

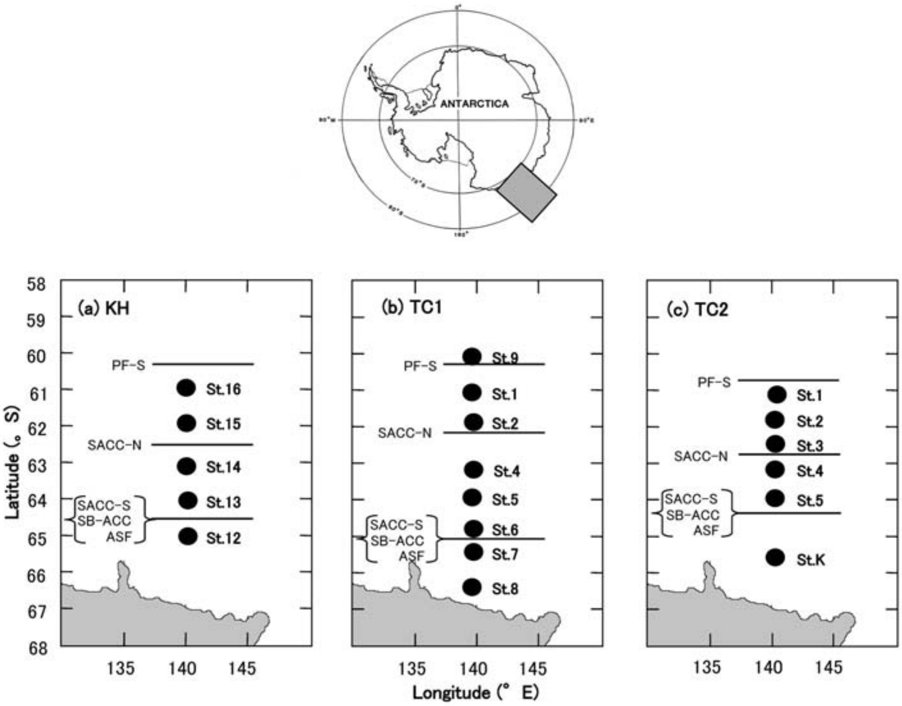

Fig. 1. Locations of sampling stations during the three cruises, (a) KH cruise (January 8–14, 2002), (b) TC1 cruise (February 13–27, 2002) and (c) TC2 cruise (February 26–March 6, 2003). Broken lines indicate the approximate locations of fronts (Aoki, et al., 2006). PF-S: southern branch of Polar Front; SACC-N: the northern branches of the Southern Antarctic Circumpolar Current Front; SACC-S: southern branches of the Southern Antarctic Circumpolar Current Front; SB-ACC: the Southern Boundary of the Antarctic Circumpolar Current; ASF: the Antarctic Slope Front (ASF)

3 knots for the TC1 and TC2 cruises. During the KH cruise, net tows were made in a depth range of about 0–1000 m. All zooplankton samples collected by these two nets were preserved in 5% (v/v) buffered formalin solution in seawater. The volume of water filtered for both nets was estimated by multiplying the effective mouth area of the net by the distance traveled measured by the flow-meter.

Sorting and counting were carried out in the laboratory. After large and fragile zooplankton (euphausiids, salps, jellyfish, *etc.*) were removed from the original sample, the rest of the macrozooplankton were sorted from 1/4 aliquot sub-sample. All of the specimens were identified to the species level or lowest possible taxon when species identification was difficult. The macrozooplankton abundance was expressed as the numbers of individuals per 1000 m^3.

Cluster analysis was done to compare macrozooplankton assemblages among sampling sites along the transect. The hierarchical fusion of clusters was carried out using the Bray-Curtis dissimilarity index with unweighted pair group averaged linkage (UPGMA), after log transforming [$\log_{10}(x+1)$] of the species abundance data.

3. Results and Discussion

According to Aoki *et al*. (2006), five oceanographic fronts were identified in the study area south of 60°S along the 140°E during the study periods. The southern branch of the Polar Front (PF-S) and the northern branch of the Southern Antarctic Circumpolar Current Front (SACC-N) were located between 60°–61°S and 62°–63°S. The southern branch of the Southern Antarctic Circumpolar Current Front (SACC-S), Southern Boundary of the Antarctic Circumpolar Current (SB-ACC), and the Antarctic Slope Front (ASF) were closely spaced in the study area between 64° and 65°S, respectively (Fig. 1). The SACCF-S and SB-ACC occasionally merged at 140°E (Sokolov and Rhintoul 2002). The SB-ACC separates two flows, the comparatively warm, eastward flowing ACC to the north and the cold westward flowing Coastal Current (CC) to the south (Hunt and Hosie 2006). The SB-ACC across the present transect is expected to one of the major biogeographic barriers of the macro scale distribution of the macro- and mesozooplankton (Tynan 1998; Nicol *et al*. 2000).

The macrozooplankton abundance was high at stations (Stns. KH-12 and KH-13) close to the SB-ACC accounting for 543–808 ind. 1000 m^{-3} and low at stations north of 63°S (Stns. KH-14, 15 and 16) ranging from 343 to 491 ind. 1000 m^{-3} in January 2002 (Fig. 2a). In February 2002 and March 2003, the highest abundance was observed at the southern most stations south of the SB-ACC (861 ind. 1000 m^{-3} at Stn. TC1-8 and 367 ind. 1000 m^{-3} at Stn. TC2-K, respectively) while showed low abundance were ob-

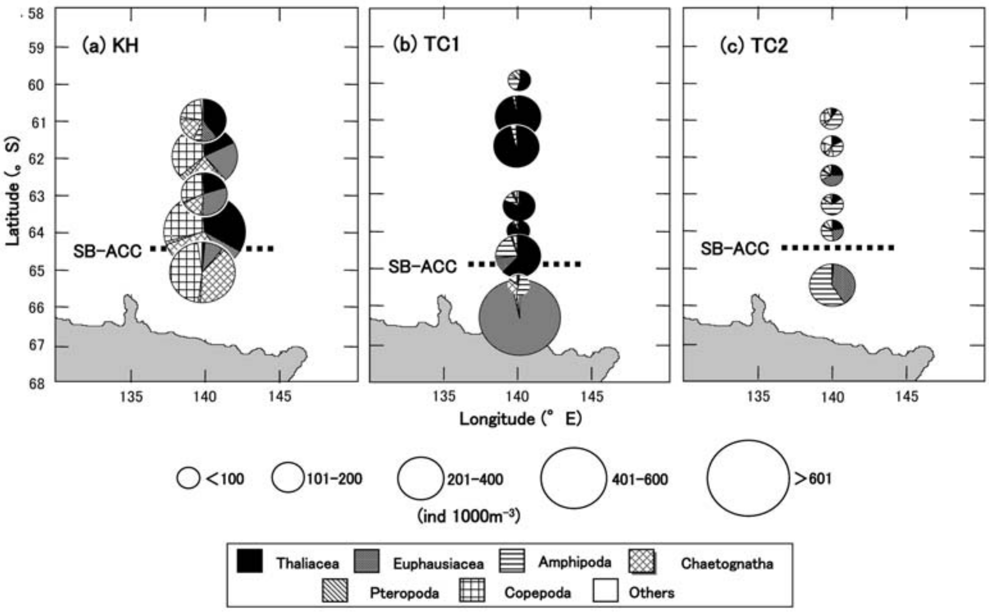

Fig. 2. Distribution and abundance of major macrozooplankton collected with RMT-8 net along 140°E transect during three cruises: (a) KH cruise (January 2002), (b) TC1 cruise (February 2002) and (c) TC2 cruise (February–March 2003). Density is expressed as numbers of individuals (ind) 1000 m^{-3}. SB-ACC: the Southern Boundary of the Antarctic Circumpolar Current

served in other stations (Fig. 2b and c).

Species diversity was higher in January 2002 compared to that in February 2002 and March 2003. Macrozooplankton were occasionally dominated by the meso-pelagic species of copepods, euphausiids or cnidarians in January 2002 samples (Fig. 2a), whereas, krill, salps, and large copepods were the important contributors to total macrozooplankton abundance in February 2002 and March 2003 (Fig. 2b and c). This is probably attributable to the difference in the sampling depth. The RMT-8 samplings in January 2002 were made in deeper layers (0–1000 m), whereas they were limited to the 0–200 m surface layer in February 2002 and March 2003.

North of the SB-ACC along 140°E, macrozooplankton assemblages were dominated by *Salpa thompsoni*. This was certainly the case in February 2002 when *S. thompsoni* almost exclusively dominated at Stns. TC1-1 and 2 north of the SB-ACC (Fig. 2b). The macrozooplankton community of the northernmost station (Stn. TC1-9) was also apparently included in the northern oceanic community, because of the dominance of the hyperiid *Themisto gaudichaudii* as well as *S. thompsoni*, the last of which is one of the indicator species of the northern oceanic community north of the SB-ACC (Hosie 1994; Hosie and Cochran 1994; Hosie *et al*. 1997). However, even at the southern stations just north of the SB-ACC (Stns. TC1-4 to 6), some typical northern oceanic species, such as *T. gaudichaudii* and *Euphausia frigida*, as well as *S. thompsoni*, were also abundant. Similar distribution patterns north of the SB-ACC were found in January 2002 and March 2003. Macrozooplankton assemblages found north of the SB-ACC in the present study area were considered to be a combination of the "main oceanic community" and "northern oceanic community" in the Prydz Bay region as described by Hosie (1994). Hosie *et al*. (2000) also found that the main oceanic community was overshadowed by the abundant *S. thompsoni* and geographically overlapped with the northern oceanic community occurring north of the SB-ACC east of 120°E as indicated by recent intensive studies on zooplankton community structure in eastern Antarctica from 90° to 150°E.

South of the SB-ACC, macrozooplankton assemblages were numerically dominated by *Euphausia superba* and/or *Euphausia crystallorophias*. Generally, *E. superba* is most abundant near the shelf edge between the oceanic and neritic zones and formed a distinct krill dominated community, while *E. crystallorophias* is found to be restricted in the continental shelf and often replaced by *E. superba* as the dominant euphausiid in shelf waters in the Prydz Bay region (Hosie 1994; Hosie and Cochran 1994; Hosie *et al*. 1997). Indeed, *E. crystallorophias* was observed only at the southernmost station in February 2002. According to recent studies in east of the Prydz Bay from 80° to 150°E, a less distinct krill-dominated community was observed, because of the low krill abundance (Hosie *et al*. 2000).

A marked change in the distribution and abundance of four large copepods was also found along the transect crossing the SB-ACC. Generally, *Calanoides acutus*, *Calanus propinquus*, and *Rhincalanus gigas* occur in circumpolar waters from the Polar Front to the Antarctic coast and they are usually found abundantly north of the SB-ACC decreasing toward the continent (e.g. Smith and Schnack-Schiel 1990; Schnack-Schiel and Hagen 1994; Atkinson 1998; Voronina 1998; Hosie *et al*. 2000). This is evident in our results of mid-summer in January and February 2002, when the abundance was high north of the SB-ACC and low south of the SB-ACC. The marked difference in abundance between north and south of the SB-ACC was mainly due to the disappearance of *C. acutus* and *C. propinquus*. They are defined as indicator species of the oceanic community together with *R. gigas* in the Prydz Bay region, as observed by Hosie and Cochran (1994). While *Metridia gerlachei* is also one of the indicator species in the Prydz Bay region, they are more abundant south of the SB-ACC and rarely occurred north of the SB-ACC. The same findings were also reported in the eastern Indian Ocean sector between 110° to 150°E by Hosie *et al*. (2000).

The cluster analysis showed two distinctive groups at the 47% dissimilarity level in January 2002 (Fig. 3a). The bifurcation point on the dendrogram did not coincide with the position of the SB-ACC, and there was a clear north-south separation of sampling stations into two groups. Group A comprised 3 stations (Stns. KH14, 15 and 16) north of the SB-ACC where the total macrozooplankton abundance was relatively low and was dominated by salp *Salpa thompsoni*, euphausiids *Thysanoessa macrura* and *Euphausia triacantha*, chaetognath *Eukronia hamata* and copepod *Calanides acutus*. Group B samples came from 2 stations (Stns. KH12 and 13) in the southern part of the study area across the SB-ACC, which was characterized by high abundance of copepods and chaetognaths.

In February 2002 and March 2003, the bifurcation point on the dendrogram coincided with the position of the SB-ACC (Fig. 3 b and c). In February 2002, one dominant group rich in zooplankton species with two distinct outliers (Stns. TC1-7 and 8) was divided at the 86% dissimilarity level (Fig. 3b). The major group comprised stations north of the SB-ACC and outlier stations TC1-7 and TC1-8 located south of the SB-ACC. Station TC1-8 was characterized by high abundance of *E. crystallorophias*, which represented 98% of total macrozooplankton abundance. Station TC1-7 had low abundances and was dominated by the hyperiid *Themisto gaudichaudii*, and the chaetognath *Eukrohnia hamata*, being 37% and 21% of the total macrozooplankton abundance, respectively. At the 53% dissimilarity level, the dominant group was further divided into two subgroups. The bifurcation point of the subgroups coincided with north-south separation of the sampling stations. The northern subgrouped stations

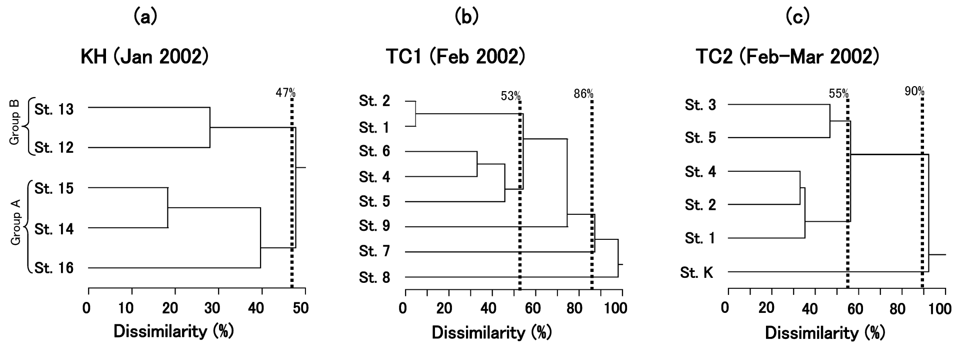

Fig. 3. Results of the cluster analysis of the macrozooplankton community structure along the 140°E transect for each cruise: (a) KH cruise (January 2002), (b) TC1 cruise (February 2002) and (c) TC2 cruise (February–March 2003). The Bray-Curtis dissimilarity index was used for the comparison.

comprised TC1-1 and 2, which were characterized by the dominance of *S. thompsoni*, while the southern subgrouped stations TC1-4, 5 and 6 mainly comprised amphipods and chaetognaths, as well as *S. thompsoni*. In March 2003, the cluster analysis showed an outlier station TC2-K based on the 90% dissimilarity level, which was the only station south of the SB-ACC (Fig. 3c), and was dominated by *E. superba* and the hyperiid *T. gaudichaudii*. Two grouped stations were identified at the 55% dissimilarity level.

The present study has provided basic information on the latitudinal distribution and structure of the macrozooplankton communities along the 140°E transect in relation to oceanographic boundaries. The SB-ACC along 140°E can be an important biogeographic boundary to separate the macrozooplankton communities as suggested by Tynan (1998). In particular, this biogeographic boundary seems to be characterized by the difference in abundance between krill and salps (Nicol *et al*., 2000).

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