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Special Issue: Ecosystem studies in the Indian Ocean sector of the Southern Ocean undertaken by the training vessel Umitaka-maru

[Editorial]
Ecosystem studies in the Indian Ocean sector of the Southern Ocean undertaken by the training vessel *Umitaka-maru*
Masato Moteki, Tsuneo Odate, Graham W. Hosie, Kunio T. Takahashi, Kerrie M. Swadling, Atsushi Tanimura

This special issue provides an overview of the ten voyages undertaken by the *Umitaka-maru* from the austral summers of 2002/2003 to 2014/2015 to promote the next phase of study of the ecosystems in the Indian Ocean sector of the Southern Ocean. The voyages by the *Umitaka-maru* have mainly targeted three areas in the Indian Ocean sector: off Dumont d'Urville Base (France, 140°E transect), off Casey Station (Australia, 110°E transect), and off Syowa Station (Japan, north of Lützow Holm Bay). The findings of *Umitaka-maru*'s research on the krill-independent food web, animal assemblages, community structure and distribution patterns from the epipelagic to the deeper waters provide invaluable information for elucidating the material cycle and predicting future ecosystem changes. Further studies on assessing the influence of sea ice on food webs in the water column are required, which will provide crucial information for predicting ecosystem changes as a result of projected sea ice changes in the near future.

Photoprotection and recovery of photosystem II in the Southern Ocean phytoplankton
Tomoyo Katayama, Ryosuke Makabe, Makoto Sampei, Hiroshi Hattori, Hiroshi Sasaki, Satoru Taguchi

The future shoaling of surface mixed layer depth due to global warming will expose natural assemblages of phytoplankton to increased mean light. Under these conditions, photoprotective acclimation against high light can determine ecological success. We investigated photoprotective responses to sunlight and recovery from photodamage of photosystem II (PSII) in natural assemblages north and south of the Polar Front (PF). The decrease in the maximum quantum yield (F_v/F_m) of PSII during direct sunlight exposure for 2 h was moderated progressively by the enhancement of diatoxanthin synthesis. When the light-exposed cells were incubated under three reduced light conditions, F_v/F_m recovered to more than the initial values north of the PF but did not reach initial values south of the PF. Temperatures higher in the north than the south of the PF could have induced the faster recovery from photodamage of PSII in assemblages north of the PF. These northern assemblages may be able to acclimate to fast-changing light conditions.

Distribution in the abundance and biomass of shelled pteropods in surface waters of the Indian sector of the Antarctic Ocean in mid-summer
Fumihiro Akiha, Gen Hashida, Ryosuke Makabe, Hiroshi Hattori, Hiroshi Sasaki

We investigated shelled pteropod abundance and biomass with a 100-μm closing net, and their estimated downward fluxes using a sediment trap installed in a drifter buoy in the Indian sector of the

Antarctic Ocean during the austral summer. Over 90% pteropod abundance was distributed in the upper 50 m; 70–100% were immature veligers. *Limacina retroversa* was dominant in the >0.2 mm individuals north of 60°S, *L. helicina* dominated south of 62°S, while populations around 60–62°S were mixed. Unidentifiable small *Limacina* spp. (ssL) were highly abundant in the upper 50 m at 60°S, 63°S, and 64°S on 110°E and 63°S on 115°E, although their estimated particulate organic carbon (POC) biomasses were less than that of *Limacina* adults. Adult females bearing egg clusters were found in the 0–50 m layer; the veligers likely grew within a short period. The mean downward flux of ssL and veligers at 70 m around 60°S, 110°E was $5.1 \pm 1.6 \times 10^3$ ind. m^{-2} d^{-1} (0.6 ± 0.2 mg C m^{-2} d^{-1}), which was 3.8% of the integrated ssL and veligers in the upper 70 m, suggesting that at least 4% of the veligers were produced daily in the surface layers. The mid-summer spawned ssL and veligers likely contributed to the subsequent increase in large pteropods in the area.

Variability of the fauna within drifting sea ice floes in the seasonal ice zone of the Southern Ocean during the austral summer

Motoha Ojima, Kunio T. Takahashi, Takahiro Iida, Masato Moteki, Naho Miyazaki, Atsushi Tanimura, Tsuneo Odate

Sea ice covering the seasonal ice zone in the Southern Ocean contains micro-organisms (sea ice biota). Studies of sea ice biota have mostly been conducted on the land-fast ice and large ice floes, despite most sea ice in the Southern Ocean being seasonal and drifting ice types. We sampled 17 drifting sea ice floes in the marginal ice zone off Adélie Land, East Antarctica, in January 2013 and 2014. We found high densities of copepods such as Harpacticoida species (18,787 ± 50,647 inds.m^{-3}), *Paralabidocera antarctica* (1773 ± 6370) and their nauplii (69,943 ± 149,607), as well as foraminiferans (193,869 ± 408,721) within ice. Variability in the animal assemblages among the different ice floes was observed. Cluster analysis of samples based on the assemblage of sea ice fauna revealed two major groups, which were divided by the year of the sampling, and were dominated by harpacticoid nauplii and foraminiferans, respectively. Sea ice trajectory and drifting duration estimated from satellite data were different for both years, although the origin of the sea ice was in the same bay. This study suggests that the variability of fauna among sea ice floes may reflect the continuance period of ice formation and the trajectory from where they originated.

Meso-zooplankton abundance and spatial distribution off Lützow-Holm Bay during austral summer 2007–2008

Ryosuke Makabe, Atsushi Tanimura, Takeshi Tamura, Daisuke Hirano, Keishi Shimada, Fuminori Hashihama, Mitsuo Fukuchi

To elucidate spatial differences in mesozooplankton community structure in local scale, vertical hauls using a 60-μm mesh closing net were carried out off Lützow-Holm Bay in January 2008. All of the zooplankton samples collected from three layers (0–100, 100–200, and 200–500 m) at seven stations were dominated by *Oithona* spp., *Oncaea* spp., *Ctenocalanus citer*, *Microcalanus pygmaeus*, and copepod nauplii. The cluster analysis of mesozooplankton abundances showed three distinct groups according to sampling depth, which appeared to be due to the preferential vertical distribution of dominant copepods. The other cluster analysis on integrated abundance upper 500 m revealed that mesozooplankton community structures at stations located on the western and eastern edges of the observation area (Cluster A) differed from those at the central stations (Cluster B). Abundance of copepod nauplii, *Oithona* spp., and *C. citer* differed between Clusters A and B, which was likely caused by differences in recruitment and early development in the dominant copepods, being associated with the timing and duration of ice edge blooms. This suggests that such heterogeneity in abundance and recruitment/development of dominant taxa was likely caused by local heterogeneity in sea ice dynamics. This may affect our understanding of zooplankton distribution.

Community structure of copepods in the oceanic and neritic waters off Adélie and George V Land, East Antarctica, during the austral summer of 2008

Aiko Tachibana, Yuko Watanabe, Masato Moteki, Graham W. Hosie, Takashi Ishimaru

Copepods are one of the most important components of the Southern Ocean food web, and are widely distributed from surface to deeper waters. We conducted discrete depth sampling to clarify the community structure of copepods from the epi- to bathypelagic layers of the oceanic and neritic waters off Adélie and George V Land, East Antarctica, in the austral summer of 2008. Notably high diversity and species numbers were observed in the meso- and bathypelagic layers. Cluster analysis based on the similarity of copepod communities identified seven cluster groups, which corresponded well with water masses. In the epi- and upper- mesopelagic layers of the oceanic zone, the SB (Southern Boundary of the Antarctic Circumpolar Current) divided copepod communities. Conversely, in the lower meso- and bathypelagic layers (500–2000 m depth), communities were consistent across the SB. In these layers, the distributions of copepod species were separated by habitat depth ranges and feeding behaviour. The different food webs occur in the epipelagic layer with habitat segregation by zooplankton in their horizontal distribution ranges.

Intra-annual seasonal variability of surface zooplankton distribution patterns along a 110°E transect of the Southern Ocean in the austral summer of 2011/12

Kunio T. Takahashi, Graham W. Hosie, Tsuneo Odate

Seasonal cycles can provide insight into the interactions between zooplankton and the environment. However, few intra-annual seasonal studies have been undertaken in the Southern Ocean. We investigated the composition, distribution, and abundance of micro- and meso-zooplankton along the 110°E meridian with three transects in December 2011, January and March 2012 using a Continuous Plankton Recorder. High zooplankton abundance was recorded in the Polar Frontal Zone (PFZ) and the Antarctic Zone (AZ) in both day and night at all transects with 179.0–300.9 ind. m^{-3}. The small copepods *Oithona similis*, *Ctenocalanus citer*, and copepodites indet (copepod indeterminable) were dominant in the PFZ and AZ communities. Total zooplankton abundance was comparatively consistent among transects. Nighttime abundance levels remained high in the AZ in March with high abundance of copepodites indet. This seasonal fluctuation appeared to be influenced by recruitment of new populations. Most core species/taxa, except for *O. similis*, *C. citer*, and foraminiferans in the AZ area in early January, exhibited a diel decrease in abundance. A multi-ship intra-annual seasonal survey will help detect their various regional and/or seasonal distribution patterns, and the impacts of environmental change on Southern Ocean pelagic ecosystems.

Spatial distributions of euphausiid species in the Northern Lützow-Holm Bay, East Antarctica during the austral summer in 2005 and 2006

Atsushi Ono, Masato Moteki

Understanding the ecology of euphausiids, especially *Euphausia superba*, is essential for understanding the Southern Ocean ecosystem. To determine the distribution and community structure of euphausiids in north Lützow-Holm Bay, we used stratified and quantitative sampling from the surface to a depth of 2000 m with an RMT 8 net in January of 2005 and 2006. Euphausiid abundance ranged from 1.2 to 32.2 ind. m^{-2}, with *Thysanoessa macrura* and *E. superba* being dominant, whereas *E. triacantha* and *E. crystallorophias* were very scarce. *T. macrura* was abundant in cold epipelagic waters as well as in the warmer Modified Circumpolar Deep Water (MCDW). *E. crystallorophias* was also observed in both the cold waters and the MCDW. The juveniles, adult males, and gravid and spent females (IIIC–E) of *E. superba* were observed in the warm MCDW, which supports the possibility of deep water spawning, as suggested by previous studies. The *E. superba* population in 2005 was composed of large, mature individuals, whereas small, immature specimens were dominant in 2006. A higher chlorophyll *a* concentration in 2005, resulting from earlier sea ice retreat, may have advanced the maturity of *E. superba*.

Spatial distribution of *Salpa thompsoni* in the high Antarctic area off Adélie Land, East Antarctica during the austral summer 2008

Atsushi Ono, Masato Moteki

The salp *Salpa thompsoni* has the potential to alter the Southern Ocean ecosystem through competition with krill *Euphausia superba*. Information on the reproductive status of *S. thompsoni* in the high Southern Ocean is thus essential to understanding salp population growth and predicting

changes in the Southern Ocean ecosystem. We carried out stratified and quantitative sampling from the surface to a depth of 2000 m during the austral summer of 2008 to determine the spatial distribution and population structure of *S. thompsoni* in the Southern Ocean off Adélie Land. We found two salp species, *S. thompsoni* and *Ihlea racovitzai*, with the former being dominant. *S. thompsoni* was distributed north of the continental slope area, while *I. racovitzai* was observed in the neritic zone. Mature aggregates and solitary specimens of *S. thompsoni* were found south of the Southern Boundary of the Antarctic Circumpolar Current, suggesting that *S. thompsoni* is able to complete its life cycle in high Antarctic waters during the austral summer. However, *S. thompsoni* was sparsely distributed in the continental slope area, and absent south of the Antarctic Slope Front, suggesting that it is less competitive with krill for food in the slope area off Adélie Land, where krill is densely distributed during the austral summer.

Measurement of the volume-backscattering spectrum from an aggregation of Antarctic krill and inference of their length-frequency distribution

Kazuo Amakasu, Tohru Mukai, Masato Moteki

Antarctic krill, *Euphausia superba*, were observed using a broadband echosounder and their length-density distribution was inferred from the echo data through a least square inversion. The observation was conducted in the Indian Ocean sector of the Southern Ocean in January 2014. The transmit signal was a 10-ms linear frequency-modulated signal with a frequency sweep of 20–200 kHz. A large aggregation of Antarctic krill was observed at a sampling station over the continental shelf. The volume-backscattering strengths in the frequency range of 85–187 kHz were determined from the observed echoes. In addition, the signal-to-noise ratio at each frequency was estimated and the measured volume-backscattering strengths were evaluated before inversion for accurate inferences. In this inversion, Antarctic krill were modeled as prolate spheroids and the target strengths were predicted by the distorted-wave Born approximation. The acoustically inferred mean length was in good agreement with the mode length determined by a net sampling performed immediately after the echo sampling. Also, the acoustically inferred length-frequency distribution was in reasonable agreement with the determined one from the net samples.

Developmental intervals during the larval and juvenile stages of the Antarctic myctophid fish *Electrona antarctica* in relation to changes in feeding and swimming functions

Masato Moteki, Eri Tsujimura, Percy-Alexander Hulley

The Antarctic myctophid fish species *Electrona antarctica* is believed to play a key role in the Southern Ocean food web, but there have been few studies on its early life history. This study examined the developmental changes in the external morphology and osteology of *E. antarctica* from the early larva to juvenile stages through the transformation phase and inferred changes in its behaviour and feeding mode. Once the larvae reached 12–13 mm body length (BL), they adopted a primordial suction feeding mode along with the acquisition of early swimming capabilities. Thereafter, both swimming and feeding functions were enhanced through fin development and ossification and acquisition of elements of the jaw and suspensorium. These processes indicate that larvae transition from the planktonic to nektonic phase upon reaching 12–13 mm BL when they enhance their both swimming and feeding abilities with growth. Transformation occurred when larvae reached 19–21 mm BL with changes such as discontinuous increases in eye diameter and upper jaw length and the appearance of photophores and dense body pigmentation. Osteological development of swimming- and feeding-related structures were mostly complete after transformation. Rapid changes in external morphology and osteology during the transformation stage are most likely related to ontogenetic vertical migration into deep waters.

Distributions of larval and juvenile/adult stages of the Antarctic myctophid fish, *Electrona antarctica*, off Wilkes Land in East Antarctica

Masato Moteki, Kentaro Fujii, Kazuo Amakasu, Keishi Shimada, Atsushi Tanimura, Tsuneo Odate

Myctophid fish are an important component of the Southern Ocean food web because of their very high biomass. This study investigated the spatial distributions of larval and juvenile/adult stages of the Antarctic myctophid *Electrona antarctica*. Fish were sampled in January 2011 and 2012 on a transect along 140°E and in January 2013 along 110°E using two different opening/closing net systems. In total, 1075 specimens of *E. antarctica* were collected: 948 larvae, 127 juveniles/adults, and 2 in the transformation stage. Most larvae were collected at 5–200 m depth, with diel vertical migration (DVM) not apparent. Larvae were mainly distributed in the Modified Circumpolar Deep Water (−1.5 °C–2.0 °C). By contrast, an analysis of the echogram at 38 kHz and discrete depth samples implied that juveniles/adults undertook DVM except in the continental slope area (65.5°S). As the distribution of krill is limited to the cold water mass (<–1.5 °C) along the continental slope, *E. antarctica* and krill populations are spatially separated off Wilkes Land during summer. According to the previously estimated larval period of 30–47 days, *E. antarctica* may spawn in late November to December in the marginal ice zone or near the sea ice edge. This study suggests that the environment related to sea ice provides a nursery ground for early stage larvae of *E. antarctica*.