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

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ABSTRACT

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*.

1. Introduction

Mesopelagic fish represent a vast amount of biomass in the Southern Ocean ecosystem, and lanternfish (Myctophidae) are a dominant family of these fish (Collins et al., 2008, 2012; Gjøsæter and Kawaguchi, 1980; Moteki et al., 2011). Of the 35 myctophid species recorded in the Southern Ocean, *Electrona antarctica* has the largest biomass and is broadly distributed in the Southern Ocean, across a wide range of latitudes from the Antarctic Polar Front (APF) to the high Antarctic zone (Duhamel et al., 2014; Hulley, 1990). Similar to krill, this species and other myctophid species are preyed upon by higher trophic level animals such as penguins, flying seabirds, and fur seals due to their high energy value for predators (Donnelly et al., 1990; Kozlov, 1995; Lea et al., 2002; Phleger et al., 1999; Saunders et al., 2014).

Murphy et al. (2007) proposed two conceptual food webs in the Scotia Sea (Atlantic sector): the krill-dependent and krill-independent food webs. In the latter, myctophids occupy a key position in the food web just under the top predators. The krill-independent food web offers an alternative to the krill-dependent food web when krill biomass is low. In the Southern Ocean, where the shelf zone is relatively narrow, krill is limited primarily to the continental slope zone (Amakasu et al., 2011; Ono et al., 2011). Total krill biomass is significantly smaller in the Indian sector than the Atlantic sector. It has been estimated that ~70% of krill biomass in the Southern Ocean is distributed in the Atlantic sector (Atkinson et al., 2008; Nicol and Raymond, 2012), suggesting that the krill-independent food web involved with *E. antarctica* has a more significant role in the Indian sector.

It is important to understand the early life history of fish to

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predict the annual fluctuation in their subsequent recruitment (Hunter, 1981). Larvae require a favorable food environment for survival during the period of initial feeding. They need to encounter food animals or particles: (i) of a size appropriate for their small mouth width; (ii) at a sufficient density; (iii) moving sufficiently slowly to be captured by the weak-swimming larvae; and (iv) of adequate nutritive quality to support the smooth changeover from endogenous (yolk and oil globules) to exogenous nutrition (Hunter, 1981; Takeuchi, 2001). Myctophid fish are known to undergo a rapid morphological transformation from the larval to juvenile stage, including in body shape, eye shape, pigmentation, and the occurrence of photophores (Moser and Ahlstrom, 1996). The morphological and functional development of *E. antarctica* has been reported by Moteki et al. (this issue), who also described the transformation at 19–21 mm body length (BL). Length of the larval period from hatching to transformation stage is estimated based on otolith increment analysis (Greely et al., 1999). Moteki et al. (2009) found ontogenetic vertical migration, with larvae changing their habitat from epipelagic to mesopelagic during a very short transformation stage. However, little information is available on the spatial distribution of early stages. Therefore, we investigated the spatial distribution and diel vertical migration (DVM) behaviour of the larval and juvenile/adult stages of *E. antarctica* using discrete depth samples collected in waters near Wilkes Land.

2. Materials and methods

2.1. Net sampling

Research cruises were conducted off Wilkes Land from 10 to 15 January 2011, 18 to 27 January 2012 (140°E transect), and 6 to 18 January 2013 (110°E transect) on the training vessel (TV) *Umitaka-maru*, belonging to Tokyo University of Marine Science and Technology. Fish were sampled at eight stations, including four stations sampled each year at 60.0–65.5°S on the 140°E transect and three stations at 60.0–64.0°S on the 110°E transect (Table 1; Fig. 1). Station D06 was situated on the continental slope. All sampling tows were conducted in open water, although pack ice was observed around the southernmost stations, D06 and D07, located near the ice edge.

Fish were sampled by an Intelligent Operative Net with Environmental Sampling System (IONESS) (1 m^2 mouth opening with 0.335 mm mesh) equipped with eight sets of opening/closing nets and a rectangular midwater trawl (RMT) 1 + 8 (1 m^2 mouth opening with 0.335 mm mesh, 8 m^2 mouth opening with 4.5 mm mesh) equipped with three sets of opening/closing nets. Two tows were conducted at each station for RMT sampling, the first from 200 to 0 m depth and the second from 2000–200 m depth. Nets were opened and closed at 2,000, 500, 200 and 100 m for the first tow, and at 200, 100, 50, 0 m for the second tow, except that the deepest sample was collected at 1400 m at Stn. D06 due to bottom depth. Two to four IONESS tows were conducted at each station, from 400 to 5 m depth, and a second cast of deeper tows was conducted along the 110°E transect. Nets were opened and closed at 400, 300, 250, 200, 160, 120, 80, 40 and 5 m (140°E and 110°E transects), and 1500, 1250, 1000, 900, 800, 700, 600, 500 and 400 m (110°E transect) (Table 1). The ship speed during net tows was 2 knots.

Samples were fixed in 5% buffered seawater formalin on board and were transferred to 70% ethanol in the laboratory before fish size measurements (140°E transect larvae) were obtained. Fish size was not measured for 110°E specimens, which were used as biomarker samples.

2.2. Hydrography and echo-sounder observation

Salinity and temperature data were collected to reconstruct the vertical profile of potential temperature along the sampling transects using a conductivity/temperature/depth (CTD) profiler (SBE-9plus; Sea-Bird Electronics) at the same stations as those at which IONESS sampling was conducted, as well as the following additional stations: 66°00′S, 140°27′E; 65°00′S, 140°00′E; 63°15′S, 140°00′E; 59°00′S, 140°00′E in 2011, 63°15′S, 140°00′E; 63°00′S, 140°00′E; 61°20′S, 140°00′E in 2012, and 59°00′S, 110°00′E; 61°00′S, 110°00′E; 62°00′S; 110°00E; 63°00′S, 110°00E, 64°41′S, 109°52′E in 2013.

Sea ice edges were detected by satellite sea ice concentration (AMSR/AMSR2 data is used for 2011/2013 and SSMI data is used for 2012; Fig. 1). Data were averaged during each research period. Here the ice edge is determined as 15 and 50% of sea ice concentration contour for AMSR/AMSR2 and SSMI data, respectively. The difference in criteria arises from spatial resolution of the data (2 and 25 km, respectively).

Echogram data of 38 kHz were taken by a hull-mounted echo sounder (Sonic Electronics, KFC-3000) in 2011 and 2012, which was calibrated during the survey each year.

Definition of the Circumpolar Deep Water (CDW) and modified CDW (MCDW) masses followed Williams et al. (2010); subsurface water warmer than 1.5 °C was defined as CDW and water between 0 °C and 1.5 °C was MCDW. The location of Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) was defined by the southern limit of maximum potential temperature warmer than 1.5 °C (Bindoff et al., 2000; Aoki et al., 2006).

2.3. Identification of Electrona species

The identification procedure for larval and juvenile *E. antarctica* followed North and Kellermann (1990) and Hulley (1990). North and Kellermann (1990) provided a provisional taxonomical key to distinguish larvae of *E. antarctica* from *E. carlsbergi*, both of which are found in the Southern Ocean. However, the key presents only one drawing of an 11.1 mm larva for *E. carlsbergi*. In general, *E. carlsbergi* is dominant north of the APF, while *E. antarctica* is distributed south of the APF (Hulley, 1990; Duhamel et al., 2014). We identified all *Electrona* larvae as *E. antarctica* based on the sampling sites being located significantly south of the APF, although no keys to separate the two species as larvae <9 mm in BL were available (North and Kellermann, 1990).

3. Results

3.1. Oceanographic conditions

The potential temperature-salinity diagrams (Fig. 2) showed curves typical of the high Antarctic Ocean, with warm, high-salinity waters on the right-top corner of the diagram referred to as CDW, MCDW between CDW and temperature minimum waters on the bottom of diagram, and warm, low-salinity surface waters on the left half of the diagram. The SB-ACC was located near Stns. D08 and D07 along the 140°E transect in 2011 and 2012, respectively, and around 63.5°S between Stns. C31 and C32 along the 110°E transect (Figs. 1 and 2). Temperature minimum waters < -1 °C were observed at all stations along the 110°E transect (60°S–64°S), while such cold waters were only at the southernmost two stations along the 140°E transect (64°S–65°30′S; Fig. 2).

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