DISTRIBUTION AND SIZE–AGE COMPOSITION OF ANTARCTIC KRILL (*EUPHAUSIA SUPERBA*) IN THE SOUTH ORKNEY ISLANDS REGION (CCAMLR SUBAREA 48.2)

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Abstract

The distribution, size–age composition and biological condition of Antarctic krill (*Euphausia superba*) caught by the Russian krill trawler FV *Maxim Starostin* in Subarea 48.2 between January and March in 2009 and 2010 are described. The distribution of size–age groups in association with particular water masses indicated that age 2+ krill dominated in cold Weddell Sea waters in the southern parts of the fishing area, while older age classes (3+, 4+, 5+) dominated in Antarctic Circumpolar Current (ACC) waters in the northern parts. No 1+ age cohort was found in catches in 2009 or in 2010. This absence of 1+ *E. superba* is unlikely to be a result of trawl selectivity as adult Pygmy krill (*E. frigida*) (of the same size as 1+ krill) were present in the catches.

Keywords: Antarctic krill, South Orkney Islands, population structure, size and age structure, maturity condition, spawning, CCAMLR

Introduction

Understanding the population structure of Antarctic krill (*Euphausia superba*) is one of the major issues for the management of krill fisheries. This includes locating areas with high and low krill spawning success. Determining the distribution of different age classes of krill is critical for studying the population structure and transport of *E. superba*. Unfortunately, it is not possible to determine the age of krill exactly. However, data in the literature on growth rates provide a sufficient basis for estimating the size–age structure of populations based on length-frequency distributions (Marr, 1962; Makarov, 1983; Aseev, 1984; Siegel, 1987; Samyshev, 1991; Candy and Kawaguchi, 2006).

Estimates of the life-span of *E. superba* range from 3 to 8 years (Marr, 1962; Makarov, 1983; Aseev, 1984; Ikeda, 1984; Candy and Kawaguchi, 2006). Nevertheless, age cohorts have been identified for juvenile krill (age 1+; modal length 25–30 mm) and 2-year-old krill (age 2+; modal length 40–45 mm); the 3-, 4- and 5-year-old krill age cohorts have a model size of 50, 55 and 58 mm respectively (Candy and Kawaguchi, 2006). These estimates are shown to be influenced by regional hydrometeorological factors (Makarov, 1983; Candy and Kawaguchi, 2006).

The aim of this paper is to present data on length-frequency distribution, size–age composition and maturity stage of *E. superba* caught by the Russian commercial trawler FV *Maxim Starostin* near the South Orkney Islands (Subarea 48.2) between January and March in 2009 and 2010.

Material and methods

Data were collected on board the *Maxim Starostin* operating in the South Orkney Islands region during the period from January to March in 2009 and 2010. In both years, fishing operations were conducted within the area bounded by 60°00.0'S–60°50.0'S and 44°55.7'W–48°00.0'W; several trawls were also conducted within the coordinates 59°35.0'S–60°01.0'S 44°14.0'W–45°37.6'W in 2009 (Figure 1). Krill were caught using commercial trawls with 14–24 mm mesh size at depths ranging from 10 to 200 m. Trawling was carried out using the conventional technique (landing of the trawl on deck), pumping the catch out of the codend with the net lifted to the surface near the vessel and the continuous pumping system with the catch pumped from the trawl codend while fishing. The full description of the configuration of these trawls is presented in Sologub (2009).

Scientific observations on board the *Maxim Starostin* were carried out according to the CCAMLR sampling protocols (CCAMLR, 2006). Krill samples were taken from the codend when using the conventional technique and from the production line when using other fishing techniques. Sologub (2009) showed that there are no differences between the length frequencies of krill caught using the continuous or the conventional fishing techniques, therefore all data were pooled for analysis. Total length (TL) and sex were determined for a random sub-sample of 200–300 individuals from each sample; further, biological analyses (including determination of maturity stage) were conducted on a random sub-sample of c.100 individuals. Species identification of euphausiids was carried out using the identification keys in Lomakina (1978), Fischer and Hureau (1985) and Gibbons et al. (1999). Krill maturity stages were defined according to CCAMLR (2006). Length and sex was determined for a total of 44 130 krill in 2009 and 2010; of these 8 066 also had the maturity stage assessed.

Hydrometeorological data were recorded daily during fishing operations. Besides, satellite sea-surface temperature (SST) data were given by the Laboratory of Fisheries Oceanography (AtlantNIRO).

Results

Hydrometeorological background

Hydrometeorological situations differed greatly between the periods of fishing in 2009 and 2010 (Figure 2). In 2009 the noon air temperature in January varied from +1.0°C to +9.5°C, in February from +1.1°C to +8.6°C and in March from +1.5°C to +4.5°C. The SST varied from +0.6°C to +1.8°C. Average SST in the research area over the period from January to March 2009 had a positive anomaly of about +0.2°C.

In January 2010, noon air temperatures ranged from –4.0°C to +5.0°C, in February from –7.0°C to +2.0°C and in March from –10.0°C to 0.0°C. The SST in 2010 varied from –0.4°C to +1.9°C, with the negative anomaly of 0°C to –0.3°C.

Despite the differences between years in absolute values, in both years the warmer waters of the Antarctic Circumpolar Current (ACC) occurred in the northern part of the fishing area and cold waters of the Weddell Sea occurred in southern parts. The position of the Secondary Frontal Zone (SFZ) (Maslennikov, 2003) varied to a considerable extent, but was situated to the north of the South Orkney Islands in both years.

Specific composition of krill (Euphausiidae)

Euphausia superba was the dominant species in the catches in both years. However, in 2009, about 500 Pygmy krill (*E. frigida*) were collected from 5 600 kg of samples (less than 0.0008% by weight); in 2010, 237 *E. frigida* were found in 730 kg of samples (0.002% by weight). The size of *E. frigida* ranged from 15 to 24 mm. All individuals of *E. frigida* were sexually mature with males having well-developed petasma and females with a thelycum.

Size and age structure

In 2009, krill ranged in size from 32 to 60 mm, forming a single dominant modal class at about 50 mm, reflecting a dominance of the 3+ age class (2006 generation) (Figure 3a). The proportion of the 4+ and 5+ age cohorts were smaller, possibly due to natural mortality of these cohorts. The 1+ age cohort was absent in catches in 2009.

In 2010 krill size ranged from 29 to 61 mm TL with a bimodal distribution (Figure 3b). Two modes were the most abundant in the catches: 43–47 mm TL, representing the age 2+ age cohort (2008 generation), and 53–55 mm TL, representing the 4+ age cohort (2006 generation). The proportion of the 3+ age cohort (2007 generation) was low. Krill of age 1+ were also absent in 2010 catches.

Statistical analysis revealed distinct correlations between male and female average length by swarms: 0.7 in 2009 and 0.8 in 2010 (Figure 4a, b). Swarms with predominantly older (3+, 4+ and 5+) and younger (2+, 3+) cohorts of krill were found. Furthermore, there were mixed swarms with intermediate mean length (Figure 4a, b). Analysis of spatial distribution of krill swarms with different average length showed latitudinal zonality in the distribution of these parameters (Figure 5a, b). Swarms of large krill (average length 50–54 mm) were found in the northern parts of the surveyed area. Swarms with predominatly smaller-size krill (average length 41–45 mm) were found in the southern costal parts of the fishing area, while mixed swarms with intermediate average length (46–50 mm) were found in a mosaic pattern in the central part of the area.

Maturity stage composition

The overall maturity stage composition of krill differed between 2009 and 2010 (Figure 6). In early January 2009, pre-spawning krill at stage IV constituted about 50% of all krill in the catches. By the end of January, the proportion of pre-spawning krill decreased dramatically (10%), and recently spent individuals (stage V) dominated the catches (Figure 7a). Gradual transition of krill from stage V to stages VI and VII (post-spawning individuals) occurred from January until March.

The maturity stage composition of krill differed in the two most abundant size groups found during 2010 (Figure 6b). The first group (43–47 mm TL; age 2+) was dominated by immature krill (stage II) throughout the period of observation. The proportion of age 2+ krill in catches varied from 5% to 95% (Figure 7b). Maturity stages IV, V, VI and VII represented a smaller proportion of this size group and occurred mainly in the northern parts of the surveyed area. The second size group (53–55 mm TL; mainly age 4+) consisted of the mature and spawning individuals. Maturity of females of this group gradually changed from stage V in January to stage VII in March (Figure 7b). Females at stage IV in January comprised less than 5% of all females in the catches. A few females at stage IV were still caught until mid-March. Males were generally at an earlier stage of maturity than females. The proportion of males at stage IV decreased from about 50% in January to 4.5% by the end of March.

Discussion

The high interannual variability in krill size and recruitment of different age classes is a result of large-scale variability of hydrological and food conditions. Differences in the size–age composition and maturity status of krill in the South Orkney Islands in 2009 and 2010 can be explained by interannual variation of food and temperature conditions, which may well be interconnected. It is possible to make inferences about krill spawning success and recruitment using the frequencies of different cohorts. For example, the krill recruitment in 2007 was apparent with only a small proportion of individuals of this generation found in catches in 2009 (age 2+) and 2010 (age 3+). Higher recruitment from 2008 was apparent, based on the higher proportion of the 2+ age cohort in 2010 (Figure 3a, b).

An important feature of the krill size–age composition in the South Orkney Islands area was the absence of the 1+ age cohort in both 2009 and 2010 (Figures 3 and 6). Similar results indicating the absence of krill less than 28–30 mm (1+ age cohort) were reported for Subarea 48.2 earlier (Makarov, 1983; Kozlov et al., 1983; Jackowski, 2002). However, several recent papers have reported the presence of juvenile *E. superba* (1+ age cohort) of less than 30 mm TL, down to 15 mm in Subarea 48.2 (Krafft and Skaret, 2009; Gulyugin et al., 2010). Consideration of this data and comparison with data in this study gives grounds to suggest that these small krill may have been misidentified *E. frigida*. It is generally known, that adult *E. frigida* and juvenile *E. superba* have the same total length and look quite similar.

There are several possible reasons explaining the absence of a 1+ age cohort in the area around the South Orkney Islands. One of the most obvious reasons is the trawl selectivity. However, it could not explain the data in this study: the trawl used on the *Maxim Starostin* caught *E. frigida* with TL of 15–to 25 mm. Had *E. superba* of the same sizes been present in swarms, it had to be present in the catches as well. This is confirmed by the analysis of the Japanese krill fishery in the Antarctic Peninsula region that showed the presence of 1-year-old krill in commercial catches (Kawaguchi et al., 1997).

Data on the occurrence of individual swarms or large areas with a prevalence of age 1+ krill in the Antarctic Peninsula and South Georgia regions are presented in several papers (Siegel, 1988; Siegel and Loeb, 1995; Loeb and Siegel, 1994; Kawaguchi et al., 1997; Watkins, 1999; Quetin and Ross, 2003). These papers describe the recruitment of krill and suggest that the main factors determining spawning success are interannual variations of food conditions and timing of ice retreat. These factors are also linked to variability in hydrometeorological parameters, such as average water temperature. The two seasons covered by this study (2009 and 2010) are distinctly different in their hydrometeorological conditions: 2009 was warm while 2010 was cold (Figure 2); despite these differences, the 1+ age cohort was absent in both years (Figure 3).

The absence of the 1+ age cohort in the area around the South Orkney Islands apparently indicates a lack of krill spawning in the previous year. This may be influenced by unfavourable conditions in the Weddell Sea (food conditions, low temperature). The development of larvae and early post-larval stages of *E. superba* is slower in the Weddell Sea (Melnikov and Spiridonov, 1996). The effect of low temperatures could also explain the absence of reproduction in the 2+ age cohort in 2010 (Figures 6 and 7).

Data in the literature on hydrodynamics of the Atlantic sector of the Southern Ocean indicates that there are two ways for krill to enter the South Orkney Islands area: ACC and the Weddell Drift (Stein, 1988; Ichii and Naganobu, 1996; Maslennikov, 2003; Murphy et al., 2007). In the latter case, the transportation occurs indirectly through the South Shetland Islands region. Melnikov and Spiridonov (1996) reported considerable densities of *E. superba* larvae at older furcilia stages (0+) and post-larval individuals (1+) in the western part of the Weddell Sea and, at the same time, rare occurrence of adult *E. superba* in that area. The authors reported on retardation of growth and ontogenetic development of krill at low temperatures and the generally northward drift of krill swarms. They also suggested that the larvae and juvenile krill were transported to the Weddell Sea from the Lazarev Sea. The data in this study suggest that these larvae and juveniles are found in the following year as age 2+ krill around the South Orkney Islands.

To the north of the South Shetland Islands, large krill (age 3+, 4+, 5+) are quickly transported by ACC waters (Ichii and Naganobu, 1996; Hofmann et al., 1998). The speed of this transport could reach 0.5 miles per hour, indicating that krill which started spawning in the austral spring in the waters of the South Shetland Islands could finish spawning at the end of summer near the South Orkney Islands. Thorough analysis of the cause and effects of the absence of the 1+ age cohort in ACC waters near the South Orkney Islands lies beyond the scope of this study. Data in the literature describe the complex pattern of westward currents from the Antarctic Peninsula (Stein, 1988; Maslennikov, 2003) and the distribution of size–age classes already in this area shows the prevalence of large-size krill to the north of Elephant Island in ACC waters (Loeb and Siegel, 1994; Siegel et al., 1997; Jackowski, 2002; Santora et al., 2010).

Conclusion

The size–age composition and maturity of *E. superba* in Subarea 48.2 are characterised by significant interannual variability. This variability is probably associated with temperature conditions and recruitment status of a season. However, two fishing seasons (2009 and 2010) showed some similarity in the distribution of size–age classes. The 2-year-old krill were dominant in cold Weddell Sea waters in the southern parts of the fishing area. Older krill age classes (3+, 4+, 5+) were dominant in ACC waters in the northern parts of the fishing area.

This study did not find juvenile *E. superba* (age 1+) in any commercial catches in 2009 or 2010. Data in the literature show in general the same absence of juvenile *E. superba* in this area. It is highly unlikely that the absence of juvenile *E. superba* was due to trawl selectivity, because adult *E. frigida* (which is the same size as juvenile *E. superba*) was present in the catches. This may reflect low recruitment of *E. superba* in particular areas that rely on the water circulation system of the Atlantic sector of the Southern Ocean to maintain krill populations. Data in this study suggest that age 2+ krill probably influx into the South Orkney Islands region after spawning successfully in the Lazarev Sea.

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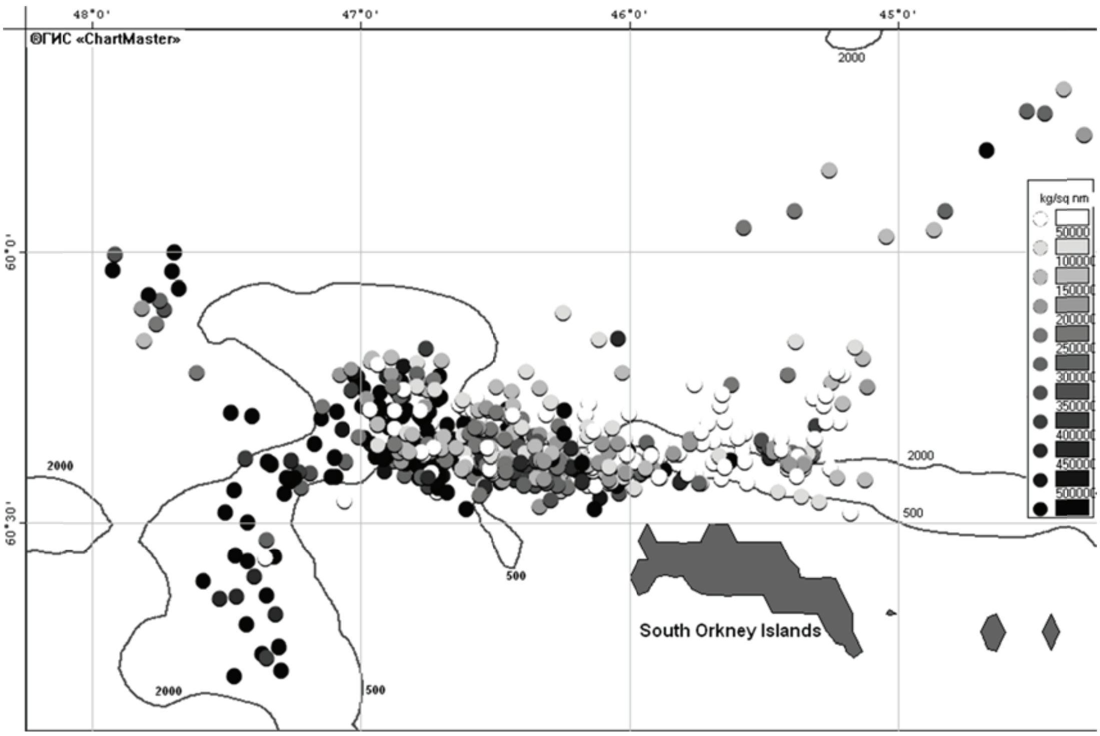


Figure 1: Location and CPUE of fishery operations in 2009 and 2010.

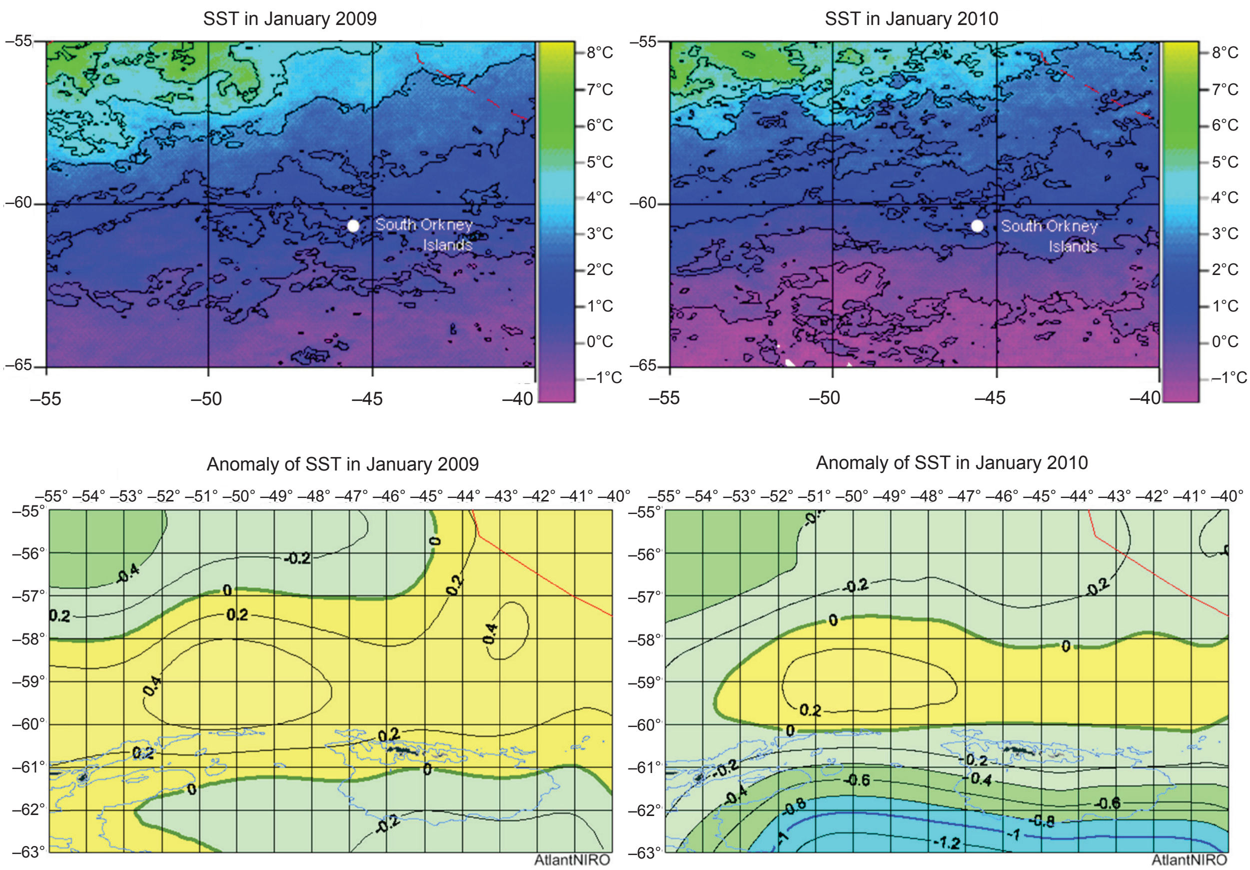
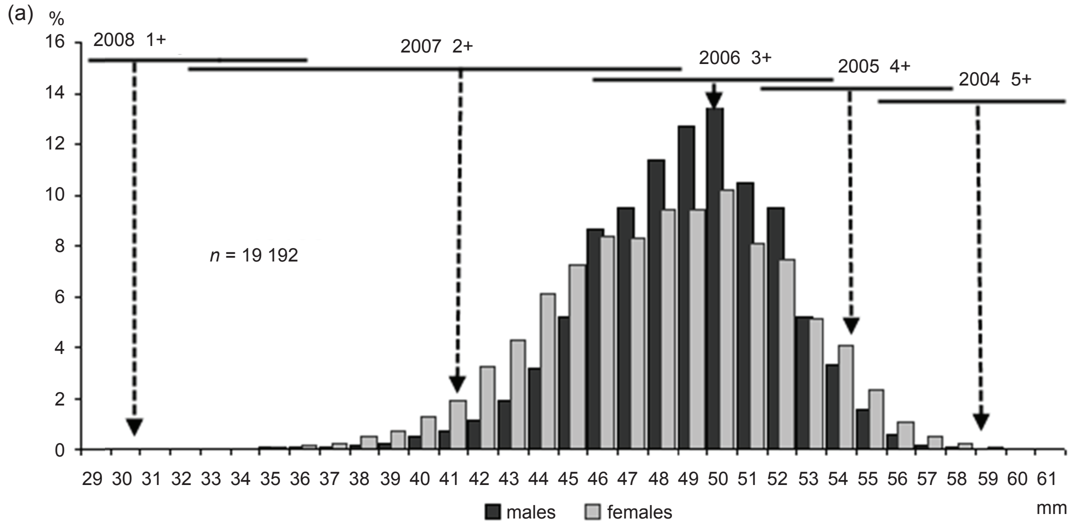


Figure 2: Hydrological conditions in the South Orkney Islands region in January 2009 and 2010.



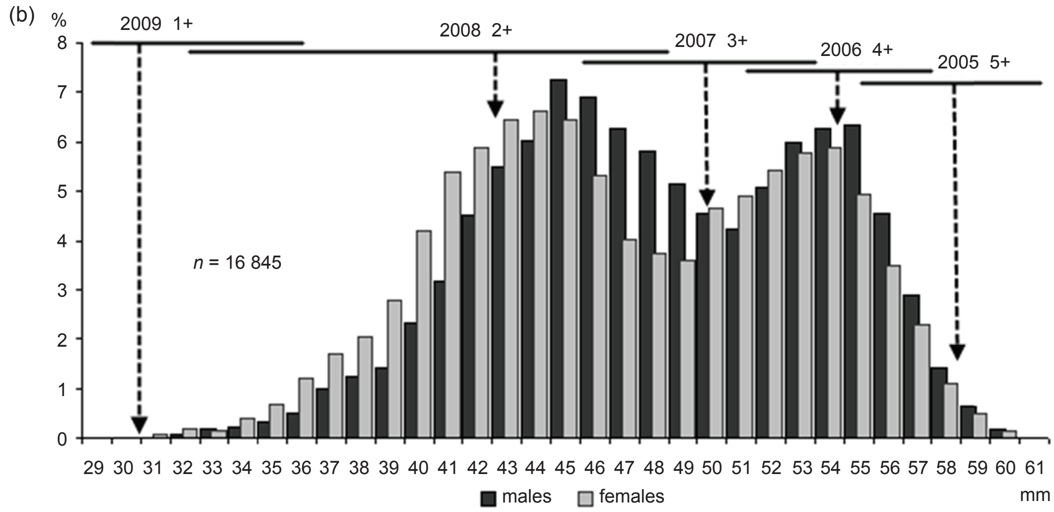
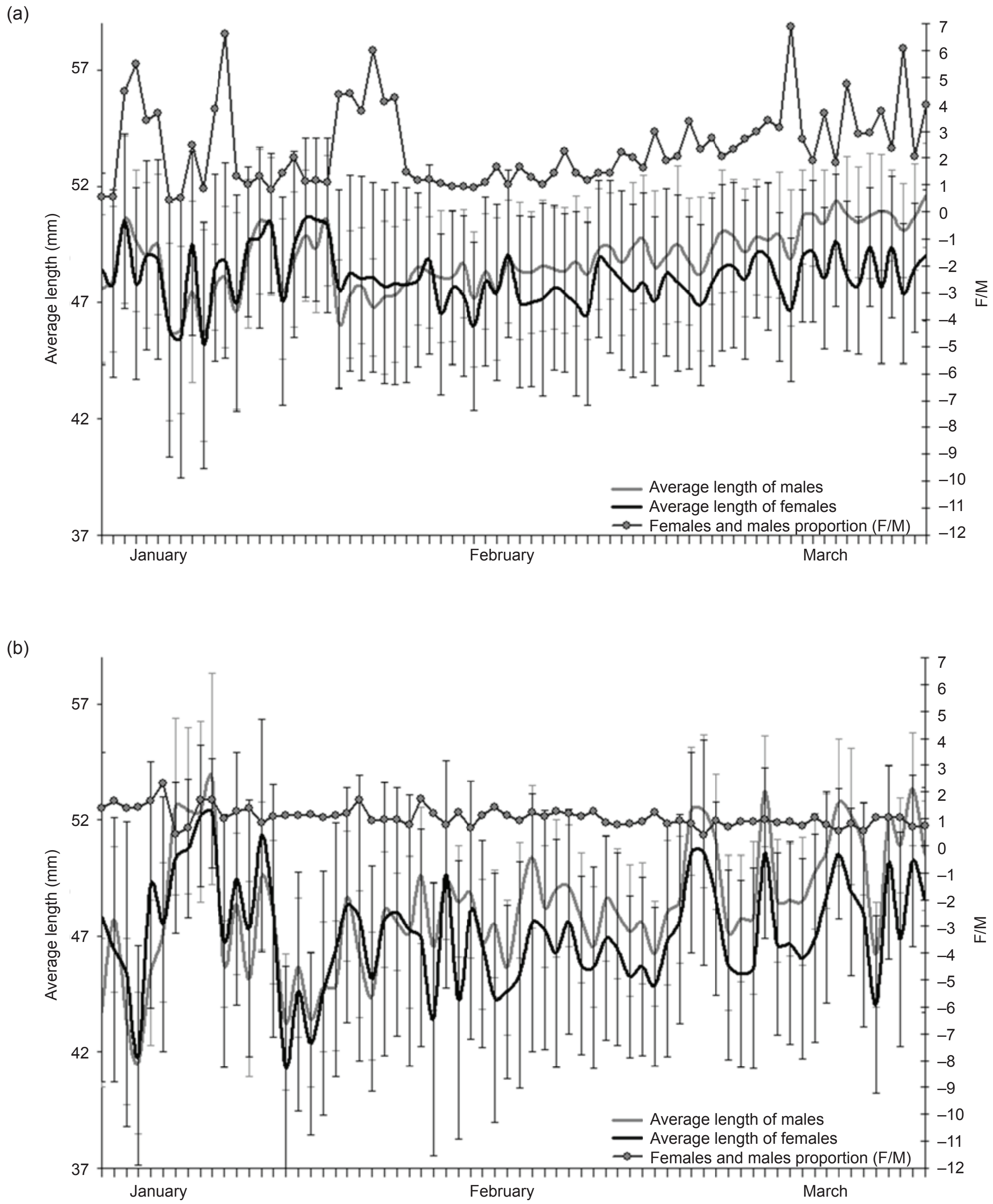


Figure 3: Size–age structure of *Euphausia superba* in 2009 (a) and 2010 (b).



Figrue 4: Average length and female:male sex ratio of *Euphausia superba* from swarms in 2009 (a) and 2010 (b).

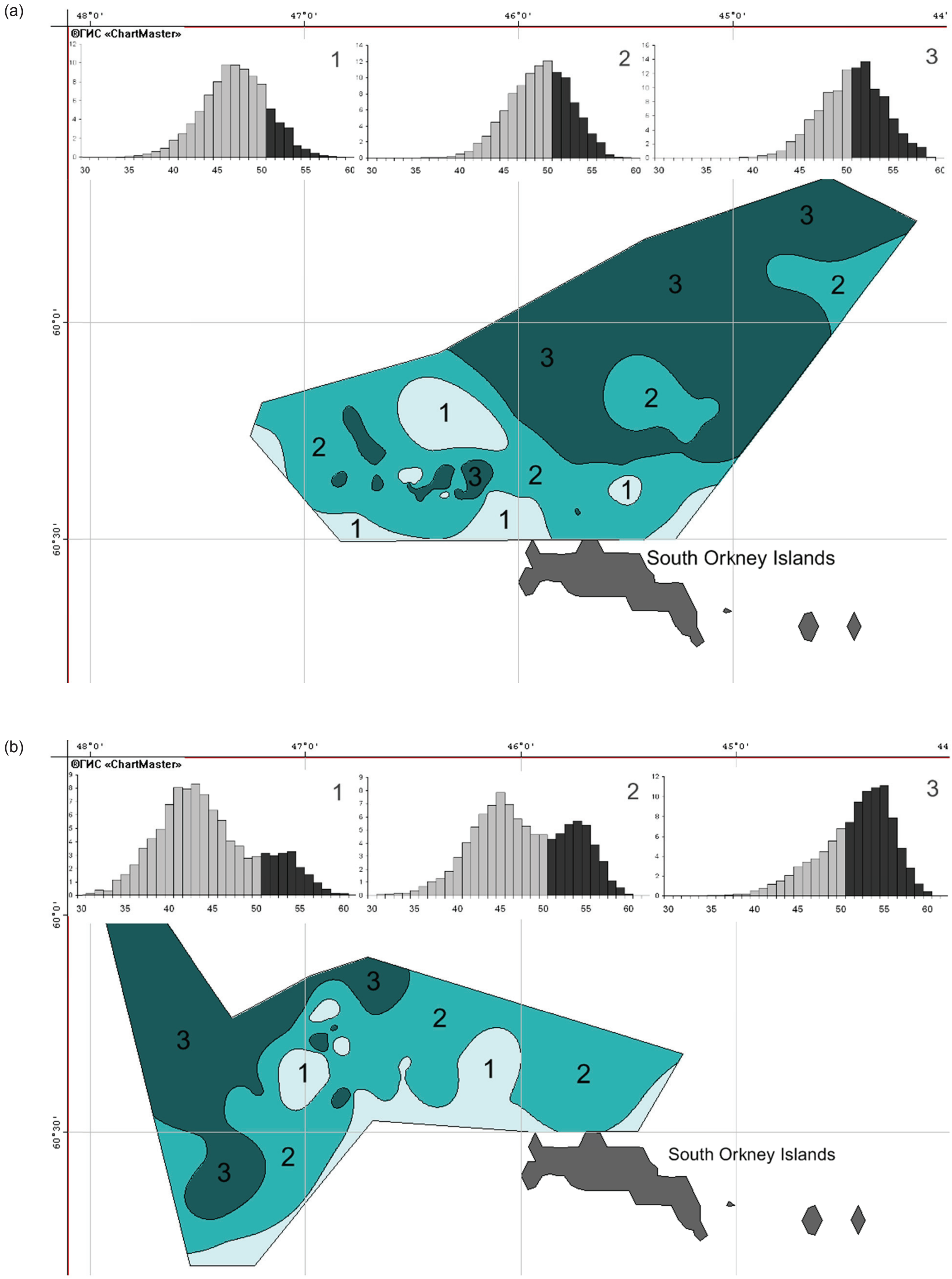


Figure 5: Distribution of the average length of *Euphausia superba* in 2009 (a) and 2010 (b). Range of average krill length in areas: 1 – 41–45 mm; 2 – 46–50 mm; 3 – 50–54 mm.

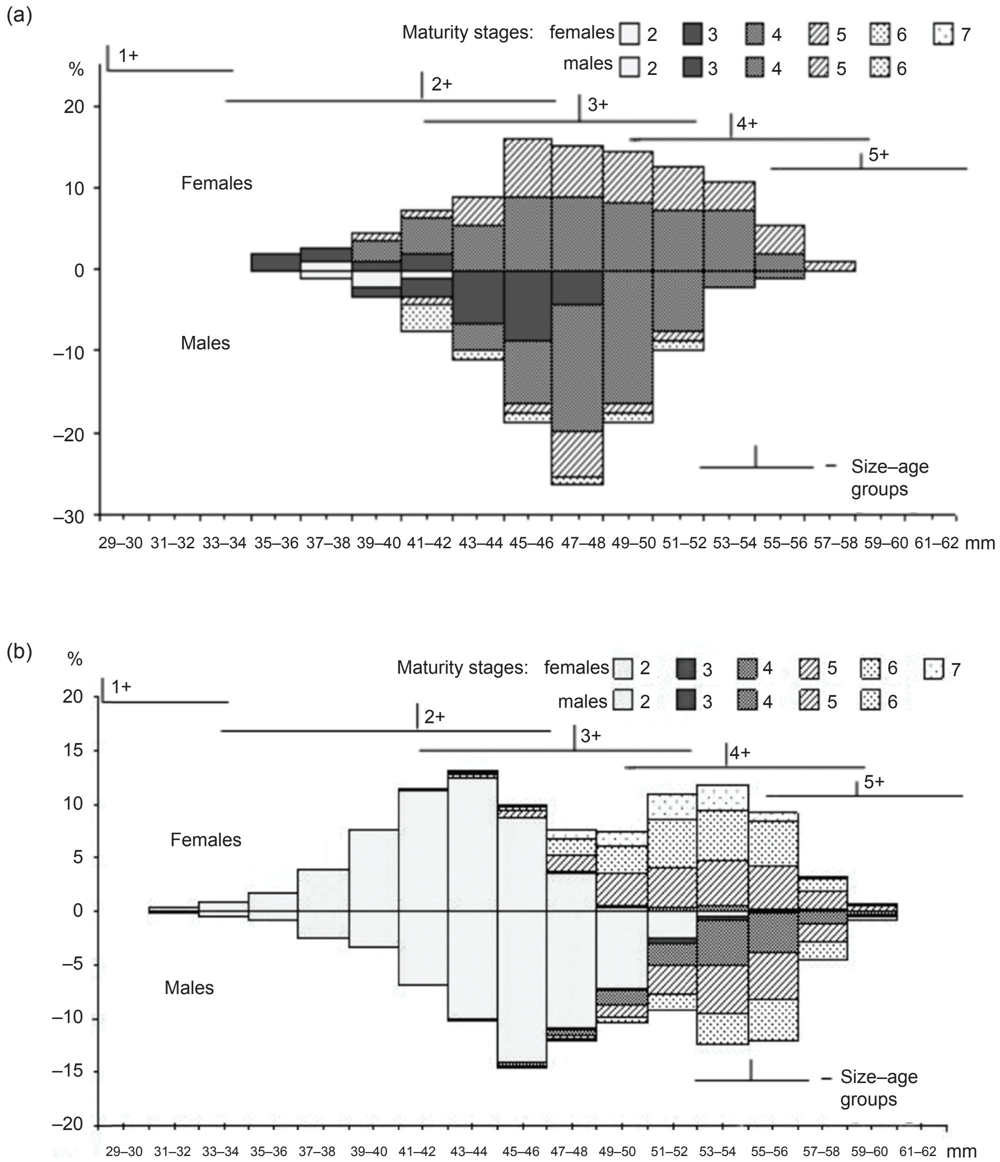


Figure 6: Size–age groups of *Euphausia superba* and their maturity stages in 2009 (a) and 2010 (b).

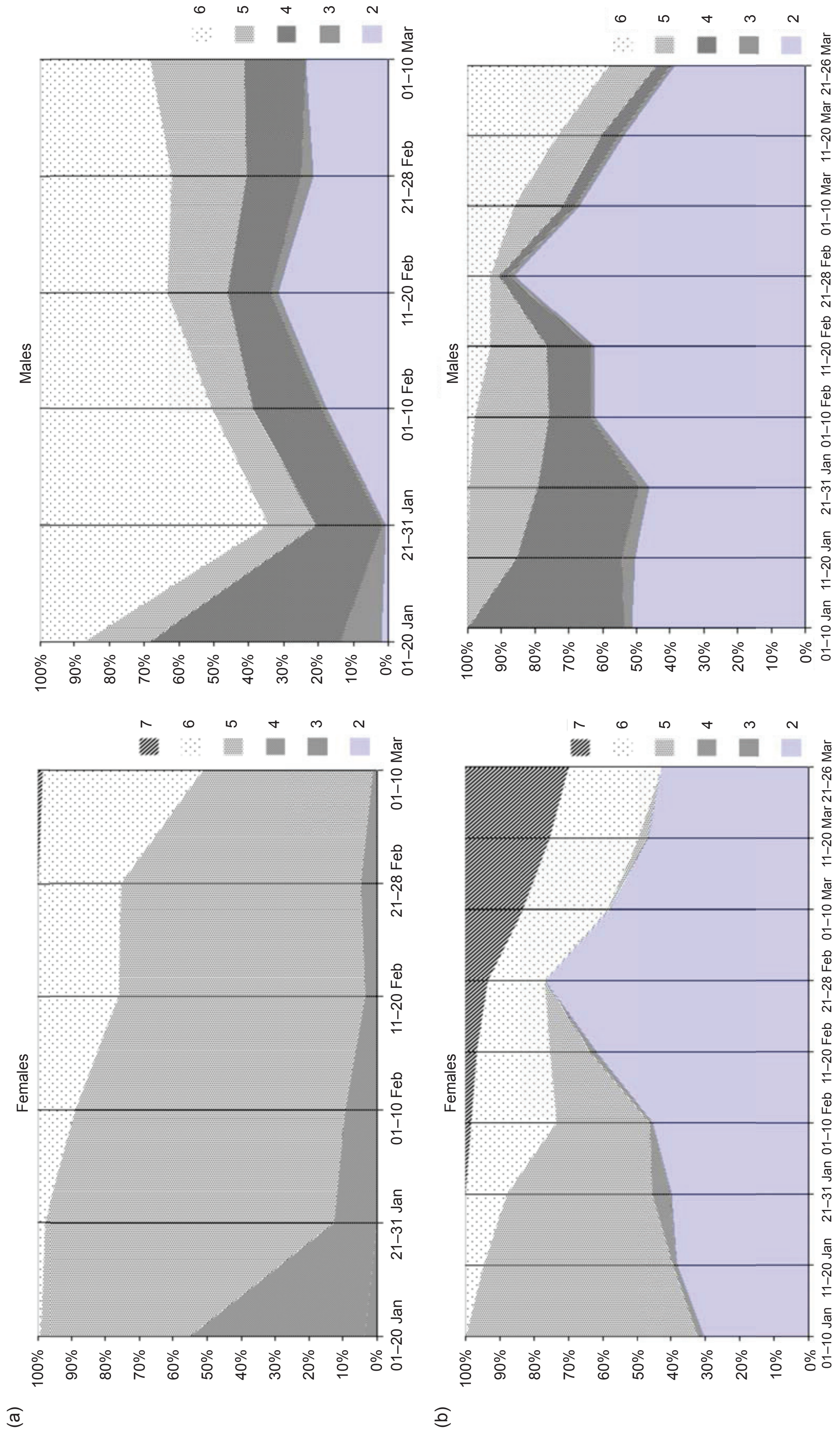


Figure 7: Maturity stages of *Euphausia superba* from January to March in 2009 (a) and 2010 (b).