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Acoustic characterisation of the broad-scale distribution and abundance of Antarctic krill (*Euphausia superba*) off East Antarctica (30-80°E) in January-March 2006

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ABSTRACT

A large-scale oceanographic survey (BROKE-West) was undertaken off East Antarctica in the austral summer of 2005/06. Throughout the survey, multi-frequency echosounder data and ancillary environmental data were collected to determine the distribution and abundance of Antarctic krill (*Euphausia superba*) and to explore its broad relationship with the bio-physical environment. The acoustic data were analysed using three different methods to provide measurements of krill abundance that can be set in context with previous studies. Based on the most recently developed acoustic method, the mean biomass-density of krill across the survey area (1.3 million km^2) was estimated to be 24 g m^{-2}. Total biomass was estimated to be 28.75 million tonnes (Mt) with a coefficient of variation (CV) of 16.18%. This biomass estimate has been used by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to update the precautionary catch limit for krill in this area (CCAMLR Division 58.4.2) from 0.450 to 2.645 Mt. Overall, krill were widely distributed at relatively low densities: 25% of the 2-km along-track echo-integration intervals were devoid of krill, 50% registered densities of 1 g m^{-2} of krill or less and 75% registered densities of 12 g m^{-2} or less. Mean densities were highest in the waters to the south of the Southern Boundary (SB) of the Antarctic Circumpolar Current (ACC), while the waters to the north of the Southern ACC Front (SACCF) were almost devoid of krill. Half of the cumulative krill density across the survey was found within 80 km of the 1000 m isobath (the shelf break), and 40% within 40 km. This was mostly due to particularly high densities (up to 4400 g m^{-2}) around the shelf break on 3 of the 11 transects surveyed. The majority of acoustic krill detections were in the top 100 m of the water column, centred around 50 m depth.

1. Introduction

Antarctic krill (*Euphausia superba*, hereafter krill) is an important species both ecologically and commercially (Everson, 2000; Nicol and Foster, 2003). Accordingly, much effort has gone into studying its distribution, abundance and other aspects of its life history. Given the extensive body of scientific literature on krill dating back 80 years or more, it is perhaps surprising to note that considerable uncertainties remain about many important aspects of krill biology and ecology (Nicol, 2006). For pelagic studies in general, such uncertainties are attributable to limitations in sampling design and instrumentation that tend to confound our ability to describe and explain species distributions (Marine Zooplankton Colloquium 2, 2001; Seuront and Strutton, 2004).

Krill surveys have typically been restricted to the relatively ice-free summer months. Surveys have been conducted at various locations around Antarctica, but the major focus has been in the South Atlantic and the islands of the Scotia Sea in particular (e.g. Atkinson et al., 2001; Reiss et al., 2008). Collectively, these surveys have resulted in a general picture of krill distribution. High concentrations of krill are often associated with island groups and the shelf-break region (e.g. Pauly et al., 2000; Hewitt et al., 2004), which unsurprisingly are also the regions most targeted by the krill fishery (Jones and Ramm, 2004). Offshore populations of krill have also been described (e.g. in the southwest Indian Ocean: Pakhomov, 2000), but the significance of this oceanic component has yet to be quantified. While the underlying nature of krill in relation to its environment is unresolved (cf. Hofmann and Murphy, 2004; Nicol, 2006), there is general agreement that the key environmental variables associated with krill life history are bathymetry, water currents, water-mass boundaries, sea-ice dynamics and food availability, even if their spatio-temporal interactions are still poorly understood (Nicol, 2006).

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BROKE-West (Nicol et al., 2010) was a single-ship, macro-scale (1000-10,000 km) oceanographic survey of the waters off East Antarctica (30-80°E) in the austral summer of 2005/06. This large-scale investigation of the pelagic ecosystem yielded a comprehensive dataset on the bio-physical environment, including along-transect multi-frequency echosounder data (acoustics). BROKE-West represents the fourth survey of this scope in the Southern Ocean, the previous three being BIOMASS (El-Sayed, 1994), BROKE (Nicol et al., 2000a) and CCAMLR 2000 (Watkins et al., 2004). Parts of the BROKE-West survey area were sampled previously during the first phase of BIOMASS (FIBEX), with the acoustic results from this multi-ship survey being used by CCAMLR (the Commission for the Conservation of Antarctic Marine Living Resources: Constable et al., 2000) to set the first precautionary catch limit for krill in CCAMLR Division 58.4.2 (30-80°E) (Trathan et al., 1992). However, the data from FIBEX are now considered outdated due to subsequent developments in instrumentation and analysis. Hence one of the primary aims of BROKE-West was to acoustically estimate the biomass of krill in Division 58.4.2 for use by CCAMLR in updating the precautionary catch limit. Having set out to collect a suite of data across the full range of trophic levels, it was also the aim of BROKE-West to contribute to a broader understanding of the structure and function of the Southern Ocean pelagic ecosystem.

In this paper, we use the BROKE-West acoustic data to estimate the biomass of krill in Division 58.4.2 and to qualitatively characterise its macro-scale distribution in relation to the bio-physical environment. We estimated krill biomass by echo-integration using three different analysis methods: Method 1 is broadly consistent with the initial analyses of BROKE (Pauly et al., 2000) and CCAMLR 2000 (Hewitt et al., 2004), Method 2 with the approach used by Demer and Conti (2005) to re-analyse the CCAMLR 2000 data, and Method 3 with the approach currently recommended by CCAMLR (CCAMLR, 2007). The presentation of results in this way provides the ability to compare between surveys that have been analysed using the three different methods. We characterised krill distribution from the echo-integration densities by comparing regional density metrics and by visualising the density measurements alongside features of the bio-physical environment that are understood to be relevant to krill life history. These results provide a foundation for further integrative efforts across the full suite of available datasets for this region, which are extensive and range from pelagic microbes to whales (Nicol et al., 2000a; Nicol et al., 2010).

2. Methods

2.1. Survey design

The BROKE-West oceanographic survey off East Antarctica (30-80°E) was conducted from the RSV *Aurora Australis* in January-March 2006. The survey was designed to collect a comprehensive, broad-scale dataset on the bio-physical environment (Nicol et al., 2010). A major component of BROKE-West was the use of hull-mounted echosounders (acoustics) to study the distribution and abundance of krill, in particular to estimate its biomass and associated variance.

The acoustic data analysed in this paper were taken from 11 north-south transects spaced at predetermined and regular 5° intervals between 30 and 80°E (Fig. 1; Table 1). The longitudinal transect lines therefore converged towards the South Pole, resulting

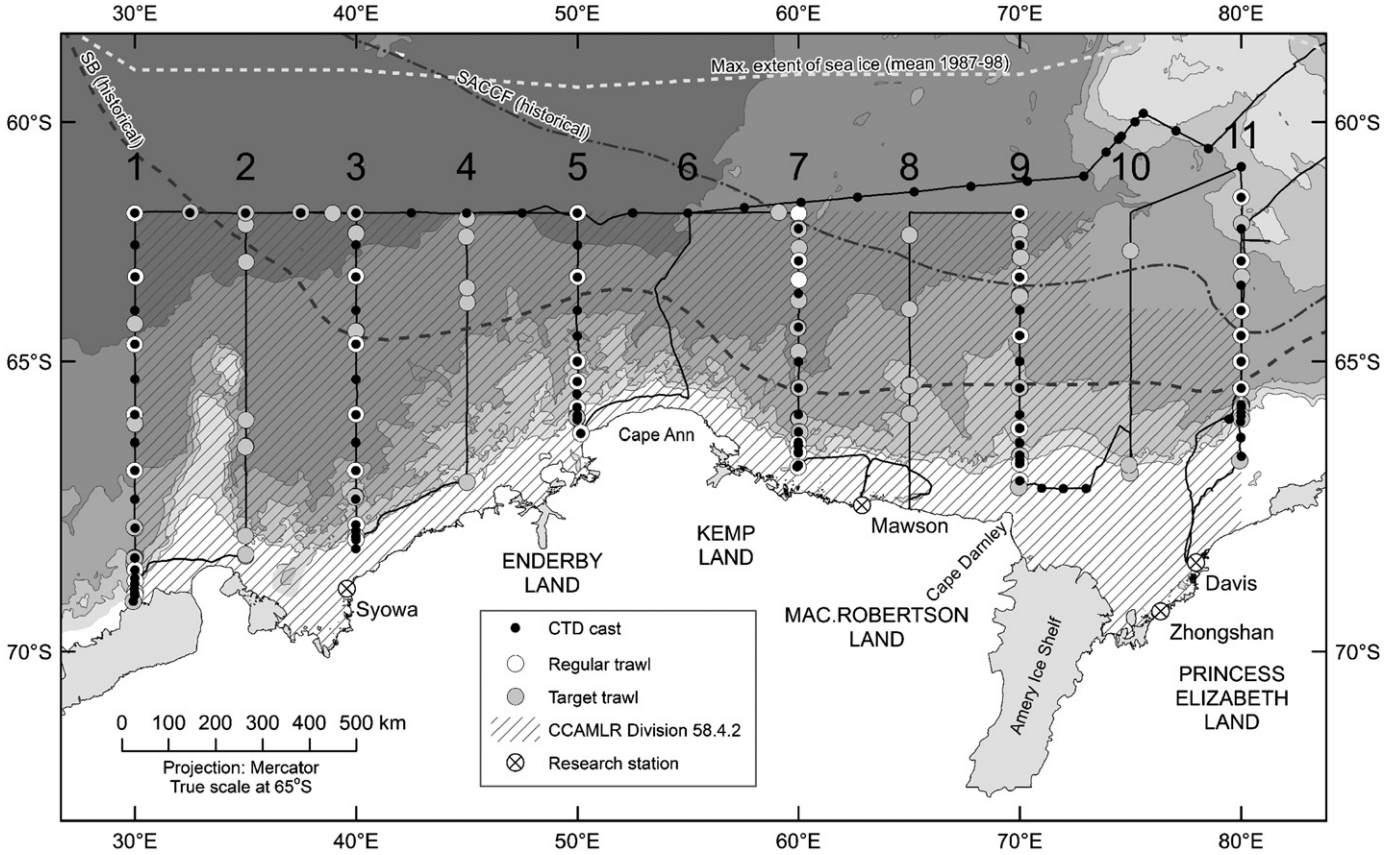

Fig. 1. Overview of the BROKE-West survey showing the cruise track, sampling stations, acoustic transect numbers and extent of CCAMLR Division 58.4.2. Bathymetric contours (GEBCO, 2003) are at 1000 m intervals. The historical locations of the Southern Boundary (SB) of the Antarctic Circumpolar Current (ACC) and Southern ACC Front (SACCF) are shown (Orsi et al., 1995), as well as the mean maximum extent of winter sea ice (Worby and Wu, 1998).