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Density of pack-ice seals and penguins in the western Weddell Sea in relation to ice thickness and ocean depth

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Abstract

Aerial band transect censuses were carried out parallel with ice thickness profiling surveys in the pack ice of the western Weddell Sea during the ISPOL (Ice Station POLarstern) expedition of R.V. *Polarstern* from November 2004 to January 2005. Three regions were surveyed: the deep sea of the Weddell Sea, a western continental shelf/slope region where R.V. *Polarstern* passively drifted with an ice floe (ISPOL), and a northern region (N). Animal densities were compared among regions and in relation to bathymetry and ice thickness distribution. Crabeater seals *Lobodon carcinophaga* were the most abundant species in all three regions. Their density was significantly lower in the deep sea (0.50 km^{-2}) than in the ISPOL (1.00 km^{-2}) and northern regions (1.21 km^{-2}). Weddell seals *Leptonychotes weddellii* were not sighted in the deep-sea region, their density elsewhere ranging from 0.03 (N) to 0.08 km^{-2} (ISPOL). Leopard seals *Hydrurga leptonyx* were observed in all three areas, but could only be quantified in the deep-sea (0.05 km^{-2}) and northern regions (0.06 km^{-2}). The abundance of emperor penguins *Aptenodytes forsteri* was markedly higher in the northern (0.75 km^{-2}) than in the ISPOL (0.13 km^{-2}) and the deep-sea region (not quantified). Crabeater seal density was significantly related to ocean depth and modal ice thickness.

Keywords: Aerial surveys; Antarctic seals; Distribution; *Lobodon carcinophaga*; Penguins; Sea ice; Weddell Sea; 66°S 58°W/69°S 38°W

1. Introduction

In the Southern Ocean, sea ice is a major factor controlling the distribution of birds and mammals (Ainley et al., 1994, 1998; Van Franeker et al., 1997; Southwell et al., 2005). For many top predators, ice provides a foraging ground, resting site and nursery platform. Changes in the extent of sea ice are thus bound to affect populations of those species (Croxall et al., 2002; Weimerskirch et al., 2003). In the Weddell Sea the distribution of pack ice is largely controlled by the Weddell Gyre (Orsi et al., 1993; Yaremchuk et al., 1998). Its clockwise transport of surface water enhances the retention of sea ice in the southern and western Weddell Sea, making it a region where significant amounts of oceanic multi-year ice persist through summer (Gill, 1973; Harder and Fischer, 1999).

Various characteristics of sea ice, including ice cover, floe size, age and structure, are closely related to ice thickness distribution. Satellite imagery does not provide sufficient small-scale detail on ice thickness, but a new method using airborne electromagnetic induction can provide high-resolution data (Haas et al., 2007a, b).

A number of bird and mammal species have developed a mode of life entirely adapted to the Antarctic pack ice. Four ice-breeding seal species are found in the Antarctic. Among them, the crabeater seal *Lobodon carcinophaga* is the most abundant (Erickson and Hanson, 1990). During the breeding period, which lasts from September to early November (Siniff, 1991; Southwell et al., 2003), its distribution may be controlled by ocean depth and sea-ice distribution (Southwell et al., 2005). The leopard seal *Hydrurga leptonyx* is less abundant but disperses more widely (Bester et al., 1995, 2002). Mother–pup pairs were observed on sea ice between early November and late

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December (Southwell et al., 2003). The Weddell seal *Leptonychotes weddellii* contrasts with the previous two species by being largely confined to coastal shelf areas (Siniff, 1991), breeding on fast ice between October and December (Reijnders et al., 1990; Lake et al., 1997; Southwell et al., 2003). The Ross seal *Ommatophoca rossii* is the least abundant species of ice seals, breeding on sea ice in the period from late October to late November (Southwell et al., 2003).

Among the penguins, only two species are fully adapted to life in ice-covered waters. The emperor penguin *Aptenodytes forsteri* even breeds on coastal fast ice during the winter period (Woehler, 1993; Kooyman, 2002). The Adélie penguin *Pygoscelis adeliae* breeds during summer in colonies on ice-free parts of the continental coast or nearby islands (Woehler, 1993; Kerry et al., 1995; Kirkwood and Robertson, 1997). The Chinstrap Penguin *Pygoscelis antarctica* is an ice species to some extent, but is restricted to more northerly areas, barely reaching the outer edge of the pack ice (Kooyman, 2002).

There is little recent information on top predator abundance in the inner Weddell Sea. A number of attempts were made to quantify seal abundance, dating from more than 20 years ago (Bonner and Laws, 1964; Siniff et al., 1970; Erickson et al., 1983). The latest report gathers data mainly collected in the eastern Weddell Sea, where pack ice was virtually absent during the survey (Bester and Odendaal, 2000). Other more recent top predator censuses concentrated on the more northern Weddell Sea pack ice and adjacent open water (Joiris, 1991; Van Franeker, 1992), the Lazarev Sea (Bester et al., 1995, 2002), east Antarctica (McMahon et al., 2002; Southwell et al., 2005) and the Ross Sea (Ainley et al., 1984; Van Dam and Kooyman, 2003).

Several publications have attempted to link top predator density to ice properties, mostly focusing on 'horizontal' properties, such as proportion of ice cover, floe size or ice type (Van Franeker et al., 1997; Bester et al., 2002; Chapman et al., 2004; Southwell et al., 2005). Only McMahon et al. (2002) included ice thickness as a variable tested to predict the distribution of crabeater seals in winter.

During the ISPOL 2004/2005 expedition, aerial ice thickness profiling surveys offered the opportunity to combine top predator censuses with on-line ice thickness measurements. This paper provides new information on the distribution and abundance of penguins and seals in the pack ice of the western Weddell Sea and discusses potential correlations of crabeater seal density with ice thickness and bathymetry.

2. Methods

2.1. Data collection

Aerial surveys of top predators and ice thickness measurements were conducted simultaneously from a BO 105 helicopter between 20 November 2004 and 4 January 2005 during the Ice Station POLarstern (ISPOL) cruise of R.V. *Polarstern* (ANT XXII-2).

Ice thickness was measured with a helicopter-borne electro-magnetic induction sensor, the so-called EM-Bird. Ice thickness was obtained as an estimate of total ice (plus snow) thickness with an accuracy of ± 0.1 m over level ice and with a spacing of 3–4 m between measurements. For further details on the accuracy and processing of EM measurements, see Haas et al. (2007a, b) and Pfaffling et al. (2007).

Censuses of top predators were conducted by a single observer (H. Flores) during flights made for ice thickness distribution mapping. Some aspects of census methods were imposed by requirements for the ice study. Most importantly, flight altitude for ice measurements was generally fixed at ± 30 m, which is well below the altitude commonly used in aerial surveys of pack-ice seals (Bester and Odendaal, 2000; Bester et al., 2002; Southwell, 2005b). Standard flight speed during the surveys was ± 80 knots (± 148 km h^{-1}).

Census methodology followed a band transect procedure (e.g., Wiig and Derocher, 1999). Because of the low altitude and relatively high speed of the helicopter, a very narrow transect width had to be used to meet the prerequisite of detection of all animals present within the band. Reference points inside the cockpit were used to identify the borders of the transect band. The cockpit reference points were constructed using markings on the heli-deck viewed by the observer in a fixed position. Distances between markings on deck were extrapolated to bandwidth at ground level when flying at standard altitude. Depending on the actual flight altitude, the width of the transect band at ground level varied from 70 to 80 m. Correctness of the reference points in identifying band width at ground level was controlled by flying over an object of known length (the *Polarstern*) at survey altitude.

Flights were conducted in three different regions (Fig. 1; Table 1):

(1) the deep-sea part of the Weddell Sea with ocean depth exceeding 2000 m (DS);
(2) the region around ISPOL where *Polarstern* was anchored to an ice floe and drifted along the western shelf-slope of the Weddell Sea (ISPOL);
(3) a region along the ship's northbound track after leaving the floe (N).

Flight tracks were designed as either two parallel transects (DS) or in a triangular pattern (ISPOL, N), in which case each side of the triangle was considered as a transect. Ice thickness measurements were made during all flights in the deep-sea and ISPOL areas, but not in the northern region. One northern flight was made exclusively for the predator survey, during which flight altitude was changed to 60 m, widening the transect band to 140 m. Ocean depth at the geographic centre point