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Responses of Antarctic pack-ice seals to environmental change and increasing krill fishing

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ABSTRACT

The compound effects of changing habitats, ecosystem interactions, and fishing practices have implications for the management of Antarctic krill and conservation of its predators. For Antarctic pack-ice seals, an important group of krill predators, we estimate the density and krill consumption in the West Antarctic Peninsula (WAP)–Western Weddell Sea area, the main fishery region; and we consider long-term changes in suitable pack-ice habitat, increased fishing pressure and potential krill declines based upon predictions from declines in sea ice cover. More than 3 million crabeater seals consumed over 12 million tonnes of krill each year. This was approximately 17% of the krill standing stock. The highest densities of pack ice seals where found in the WAP, including in its small-scale fishery management areas, where apparently suitable seal habitat has declined by 21–28% over a 30 year period, where krill density is likely to have declined, and fishing has increased. The highest seal density was found in the Marguerite Bay area which is a source of krill for the Antarctic Peninsula and elsewhere. Significant sea-ice loss since 1979 has already occurred, leading to open water and possible expansion for the fishery in the future. These factors may combine to potentially reduce food for pack ice seals. Therefore, high uncertainty in krill and seal stock trends and in their environmental drivers call for a precautionary management of the krill fishery, in the absence of survey data to support management based on specific conservation objectives for pack-ice seals.

1. Introduction

Antarctic krill (*Euphausia superba*) is most abundant in the Scotia Sea, Antarctic Peninsula and Western Weddell Sea regions where more than half of the world's biomass is thought to be present (Atkinson et al., 2009). It is a keystone species that sustains millions of predators, and a fishery that operates almost exclusively in this area but is currently thought to under-exploit the potential yield of the stock (Nicol et al., 2011). Increasing habitat deterioration, ecosystem fluctuation and new fishing practices combine to create a high level of uncertainty that needs to be incorporated within fisheries management. In this region, a specific management objective is to prevent irreversible declines in krill-dependent predators and this includes the crabeater seals (*Lobodon carcinophaga*).

In the Scotia Sea–Weddell Sea region, pack-ice seals and specifically crabeater seals have been identified as the major krill consumers (CCAMLR, 2008); over 90% of crabeater seals' diet is estimated to be krill. Krill is also important for leopard seals (*Hydrurga leptonyx*), but may be less important for Weddell (*Leptonychotes weddelli*) and Ross seals (*Ommatophoca rossii*) (Laws, 1984; Øristland, 1977; Siniff and Stone, 1985). In recent decades, rapid environmental change (Meredith and King, 2005; Parkinson, 2004; Stammerjohn et al., 2008;Whitehouse et al., 2008) is having a significant effect on some populations of different krill predators (Ducklow et al., 2007; Forcada et al., 2006, 2008; Fraser and Hofmann, 2003; Trivelpece et al., 2011). For pack-ice seals, climate change leads to sea ice loss, which reduces suitable breeding and resting habitat. Sea ice also affords protection from predators (Siniff et al., 2008; Costa et al., 2010), and its loss also increases the distance to areas that concentrate prey (Burns et al., 2004; Southwell et al., 2005). Sea ice loss has also been associated with declines in krill biomass (Atkinson et al., 2004), particularly in the West Antarctic Peninsula region, where predator responses to regional

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warming over recent decades suggest a less predictable krill supply (Fraser and Hofmann, 2003; Trivelpece et al., 2011).

The loss of winter sea ice in the Antarctic Peninsula has also allowed a temporal and geographical expansion of the krill fishery, coupled with new markets and technologies (Kawaguchi et al., 2009; Nicol et al., 2011). Consequently, total catches and catch rates per vessel have increased significantly over the last decade (CCAMLR, 2011; Nicol et al., 2011), especially in FAO management Area 48.1 which includes parts of the Scotia Sea, the Western Weddell Sea (WWS), and the WAP (Fig. 1). Even though current fishing is thought to be sustainable, because catches are extracted mainly from coastal areas where predators have a limited capacity to shift distribution in response to local depletion by a fishery (Trivelpece et al., 2011), there are concerns about the effects of the fishery on krill populations and krill predators (e.g. Schiermeier, 2010). While a procedure for small-scale area management has been advocated (Hewitt et al., 2004), it does not take into account uncertainty associated with observed sea ice loss or a potentially declining krill biomass and the consequences for predators.

In this paper we consider the consequences of climate change and increased krill fishing for Antarctic pack-ice seals. We: (1) report the density of pack-ice seals in the WAP–WWS area in relation to the sea-ice environment, at a resolution compatible with the krill fishery small scale management areas; (2) address the long-term change, from 1979 to 2011, in suitable pack-ice seal habitat; (3) relate estimated krill consumption of pack-ice seals to available biomass, as estimated in a synoptic survey in 2000, and commercial extraction in Area 48.1; and (4) address the regional sensitivity of pack-ice seals to trends in the physical-biological environment and the fishery operation.

2. Materials and methods

2.1. Study area and data collection

The study area lies between 90° and 30°W and 80° and 60°S (Fig. 1). Particular sub-areas of interest were: the WAP and WWS, separated at the northernmost tip of the Antarctic Peninsula (approximately 63.5°S); the Marguerite Bay area (MBA), between 78° and 66°W and 70–66.5°S; and FAO Area 48.1, which includes specific Small Scale Management Units (SSMUs; Hewitt et al., 2004), where the krill fishery operates. Seal habitat was considered to be the pack-ice, limited by the ice-edge and areas covered by fast-ice, shelf-ice, continental-ice or ice-free land. The ice edge was defined using the bootstrap algorithm for sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I (Comiso, 1999), producing a composite sea ice map for the survey period with 0.2° lat/lon grid cell resolution.

Pack-ice seal line-transect data were collected in an aerial survey conducted as the UK contribution to the Antarctic Pack Ice Seals (APIS) programme (Anonymous, 1995). The survey occurred between 22 and 29 January 1999, using a De Havilland Canada DHC-6 Series 300 Twin Otter aircraft operated by the British Antarctic Survey. Transects were placed to effectively sample the pack-ice habitat according to its configuration on the West and East sides of the Antarctic Peninsula (Fig. 1), given the range limits and operational capacity of the aircraft. Transects did not follow a systematic design.

Observers at each side of the aircraft searched for seals hauled out on ice, measuring perpendicular distances to the trackline from the aircraft to sightings of seal aggregations while flying at constant speed and altitude. A semi-automated system (Southwell et al., 2002) logged the data to ensure maximum sighting efficiency. In one transect, paired observers searched independently on the same side of the aircraft to collect double observer data to estimate detectability bias on the trackline. Effects of *observer* (*ob*), *group size* (*gs*), and *species* (*s*) were collected to model heterogeneity in detectability. *Species* had four categories: *cs* crabeater, *ws* Weddell, *ls* leopard, and *us* unidentified seal; Ross seal sightings were only confirmed on one occasion and thus were excluded from the analysis. Visibility directly underneath the flying path was obstructed within the first 100 m to each side of the aircraft.

Year round seal activity data with daily resolution, partitioned when possible as duration of haul-out (*h*), diving (*d*), and at the

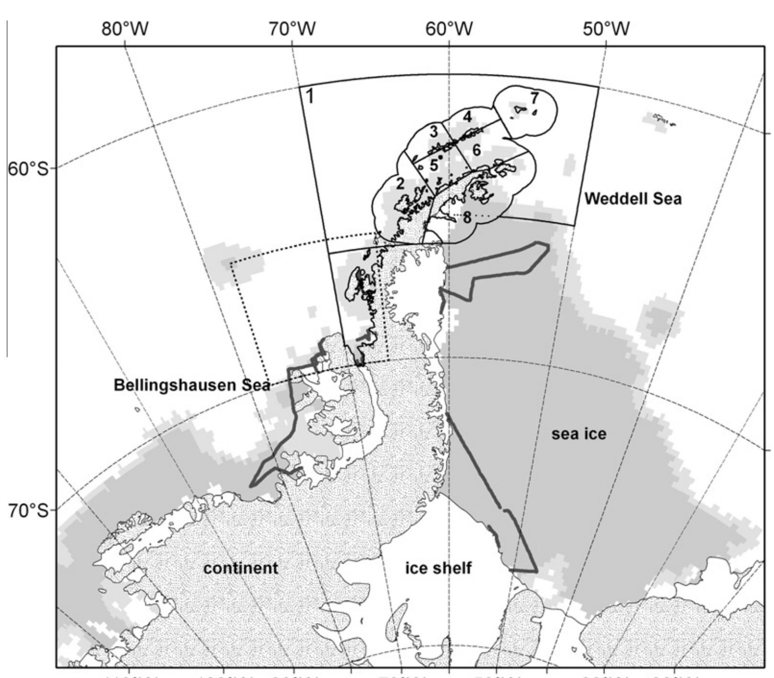

Fig. 1. Study area with aerial survey effort (thick line) for pack ice seals between 22 and 29 January 1999 (thick solid lines). FAO Area 48.1, including numbered CCAMLR SSMUs (solid line polygon), MBA (dotted line polygon), and sea ice environment. Sea ice concentration of 25% or above is in darker grey; ice concentrations below 15% are less reliable. FAO Area 48.1 extends to 70°S including the Marguerite Bay area, but with a lower longitudinal extent than the dotted area delimitation.