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Identifying overlap between humpback whale foraging grounds and the Antarctic krill fishery

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ABSTRACT

The Antarctic krill fishery is the largest in the southern ocean, but currently operates without fine-scale information on whale movement and behavior. Using a multi-year dataset of satellite-tagged whales, as well as information on krill catch levels, we analyzed the spatial distribution of whales and fisheries effort within the small-scale management units defined by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). Using a Bayesian movement model to partition whale movement into traveling and area-restricted search states, we found that both whale behavior and krill catch effort were spatially clustered, with distinct hotspots of the whale activity in the Gerlache and southern Branfield Straits. These areas align with increases in krill fishing effort, and present potential areas of current and future conflict. We recommend that the Antarctic West and Bransfield Strait West management units merit particular attention when setting fine-scale catch limits and, more broadly, consideration as critical areas for krill predator foraging.

1. Introduction

Minimizing overlap between fishing effort and predators is a persistent challenge in managing marine fisheries. To create ecologically informed guidelines, managers need detailed information on occurrence, abundance and behavior of predator species. This is especially difficult in polar regions where information can be scarce and observation windows are curtailed due to extreme climate. High-resolution tracking data provides a bridge between species locations and geographically dependent behaviors (Hays et al., 2016). By incorporating behavior into conservation action, we gain greater insight into the threats animals face, and increase the likelihood that management plans achieve positive conservation goals (Ellison et al., 2012 Trathan et al., 2015).

The Antarctic krill (*Euphausia superba*) is the keystone species of the Antarctic ecosystem, providing the primary food source for a diverse group of predators including fish, penguins, seals, and whales (Hill et al., 2006). Antarctic krill form dense swarms, sometimes in excess of 10,000 individuals per cubic meter, extending 200–300 m in depth and several kilometers wide (Tarling et al., 2009, Nowacek et al., 2011; Espinasse et al., 2012). The Antarctic Krill fishery is the largest in the Southern Ocean with a reported total catch of 293,815 metric tonnes (mt) in 2015. This catch has fluctuated greatly, with a peak of nearly 500,000 mt in the 1980s, to a low of < 100,000 mt in the early 2000s, to a rapid increase to 300,000 mt since 2009 (Nicol et al., 2012). This rise is due to the expansion of the fishery by new nations, as well as an extension of fishing effort into austral autumn and winter months (CCAMLR, 2015).

The krill fishery is managed by the Commission for the Conservation of Marine Living Resources (CCAMLR). CCAMLR was formed in 1982 as part of the Antarctic treaty system with the goal of 'providing maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine resources' (Constable et al., 2000). The CCAMLR management guidelines require that the krill fishery not interfere with the population growth of Antarctic krill predators (Kawaguchi et al., 2006). However, the management of the krill fishery has not assessed the needs and behavior of baleen whales, which are the largest krill predators in the Antarctic.

The krill fishery historically included large expanses of Antarctic waters, but is currently concentrated in the South Atlantic (FAO statistical Area 48). Records from 2015 report 146,191 mt taken from the Antarctic Peninsula and South Shetlands Islands (Subarea 48.1), 72,455 mt from the South Orkneys Islands (Subarea 48.2), and 75,169 mt from South Georgia Island (Subarea 48.3) (CCAMLR, 2015). Our study focuses solely on subarea 48.1 (Fig. 1), an area of increasing importance to the fishery. The current precautionary annual

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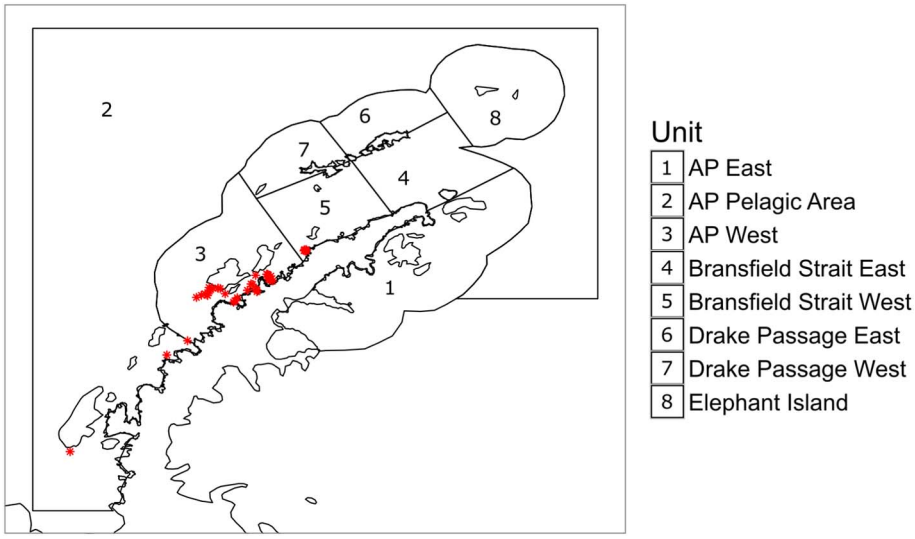

Fig. 1. CCAMLR small-scale management units for the West Antarctic Peninsula krill fishery (CCAMLR Sub-unit 48.1). For brevity "Antarctic Peninsula" is abbreviated AP.

catch limit of 5.61 million mt is shared among all subareas, and is substantially more than the total annual catch (Nicol et al., 2012). In 2009 CCAMLR adopted an interim measure (Conservation Measure 51-07) to distribute 620,000 mt of catch limit across subareas, with a limit of 155,000 mt for subarea 48.1. This level has been reached four times since 2010, with each event leading to the closure of the subarea for the remainder of the season (Nicol and Foster, 2016). CCAMLR has attempted to further manage the spatial distribution of fishing effort by agreeing upon small-scale management units (SSMUs; Fig. 1). However, to date, CCAMLR has failed to agree on a method to distribute the total precautionary catch limit between SSMUs (Hewitt et al., 2004). Our aim is to determine the overlap between the krill fishery and areas of whale foraging, in order to recommend whether specific small-scale management units should have restrictions in fishing effort or duration.

Since the cessation of commercial whaling in the Southern Hemisphere in the late 20th century, humpback whales (*Megaptera novaeangliae*) have recovered to become the most numerous whale species in the region (Clapham et al., 1999 Herr et al., 2016 Matsuoka et al., 2006). Previous work has shown that humpback distribution is related to the distribution and abundance of krill (Friedlaender et al., 2006 Nowacek et al., 2011). At the fine-scale, the foraging behavior of humpback whales is affected by the depth and density of krill patches, due to the energetic demands of whale foraging and life-history (Friedlaender et al., 2013 Tyson et al., 2016). Humpbacks whales may therefore be vulnerable to disturbance from the krill fishery due to their reliance on krill as a primary food source (Nicol et al., 2008). Current information on the foraging behavior of Antarctic humpback whales comes largely from short-term tagging efforts (e.g. Friedlaender et al., 2013 Johnston et al., 2012), and from ship-based surveys (Hedley et al. 2001 Herr et al., 2016 Santora et al., 2010). We used a large multi-year dataset (> 40,000 Argos locations) of tagged humpbacks to assess the space use and behavior within CCAMLR small-scale management units. Our goals are to 1) describe the areas of humpback presence in reference to the CCAMLR small-scale management units, 2) partition movement into traveling and area-restricted search states, and 3) compare the areas of whale behavior with the distribution of krill fishery activity along the Antarctic Peninsula.

2. Methods

2.1. Satellite tagging and tracking

We deployed Wildlife Computers (Redmond, WA, USA) SPOT5 Platform Transmitting Terminals (PTTs) in 2012, 2013, 2015, and 2016 (Table S1). Each tag is contained in a sterilized housing designed to penetrate the whale's skin and blubber up to 290 mm, and is anchored in the tissue beneath the blubber with stainless steel barbs, with the transmitting antenna remaining free outside of the animal. Tags were deployed by experienced researchers from a Zodiac Mark V or a Solas ridged-hulled inflatable boat with a 40 hp 4-stroke engine using an ARTS Whale Tagging PLT compressed air system. Whales were approached at idle speed from oblique angles so as not to cross over the flukes. No dependent calves were tagged, all whales were presumed to be adults based on their size. Tags were deployed from a range of 3–10 m and placed near the dorsal fin, which contains the thickest blubber layer, and also provides the greatest height to transmit positional information via the exposed antenna.

All tags transmitted positional information via the Argos satellite system and were activated via a salt-water switch. In 2012, tags transmitted only during the hours 00:00–04:00 and 12:00–16:00 GMT. All subsequent tags were set without duty cycling and attempted to transmit data on each surfacing. Our raw data included 46,421 observations for 42 humpback whales from 2012 to 2016. We filtered observations without location data (n = 103), duplicate timestamps (n = 186), locations on land (n = 1800), and implausible speed between consecutive locations (n = 2552) to create a filtered set of observations. The duty cycle from the 2012 tags made it difficult to use tracks with large gaps and they were removed (n = 6). From this initial dataset, we kept tracks that had points within 6 h intervals, and discarded tracks < 24 h (Fig. S1).

2.2. CCAMLR units krill fishery data

Commercial krill catch data were provided with permission by CCAMLR for Subareas 48.1–48.4, aggregated into 0.5° latitude and 1.0° longitude grid cells. CCAMLR's small-scale management units range in size from 16,000 km^2 to 440,000 km^2 covering the northern section of the Antarctic Peninsula to south of Anvers Island (Fig. 1). Krill catches in kg were used from 1980 to 2015 and summed across all CCAMLR member nations. Catch is reported on a haul-by-haul basis, on either monthly or 5-day intervals, depending on the amount reported. The haul-by-haul data requires locations for start and end fishing positions. For analysis, the total amount of krill collected in each georeferenced grid cell was aggregated across seasons to represent the catch intensity in the waters surrounding the western side of the Antarctic Peninsula (Fig. 2).