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Bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea

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ABSTRACT

We examined the response of bowhead whale (*Balaena mysticetus*) body condition to summer sea ice conditions and upwelling-favorable winds. We used a long-term dataset collected from whales of the Bering–Chukchi–Beaufort Seas (BCB) stock to estimate various body condition indices (BCI's) for individual whales that were harvested by Alaskan Eskimos. A series of offshore regions frequented by bowhead whales in summer were delineated and used to quantify interannual summertime environmental conditions including: (a) mean open water fraction, (b) duration of melt season, (c) date of continuous freeze-up, and (d) mean upwelling-favorable wind stress. Body condition was analyzed relative to these metrics for both the preceding summer feeding season and the previous three seasons combined. Our analysis indicates a significant increase in the long-term trend in an axillary girth-based body condition index (BCI_G) over the study period (1989–2011). The increase in BCI_G is likely associated with the trend in overall reduction of sea ice, including increased duration of open water, changes in upwelling potential (wind stress), and possibly higher primary production in the Pacific Arctic marine ecosystem favoring water-column invertebrates. We found strong significant positive correlations between BCI_G and late summer open water fraction in the Beaufort Sea and smaller nearshore areas off the Mackenzie Delta and west of Banks Island. Additionally, BCI_G was positively and significantly correlated with duration of melt season, later date of freeze-up in the Beaufort Sea, and upwelling-favorable winds on the Mackenzie shelf and west of Banks Island. A strong seasonal difference in BCI's was noted for subadult bowheads, presumably associated with summer feeding; however, yearlings were found to drop in BCI over at least the first summer after weaning. Our results indicate an overall increase in bowhead whale body condition and a positive correlation with summer sea ice loss over the last 2.5 decades in the Pacific Arctic. We speculate that sea ice loss has positive effects on secondary trophic production within the BCB bowhead's summer feeding region. While not part of this study, the abundance of BCB bowheads increased markedly over the same period.

1. Introduction

The bowhead whale (*Balaena mysticetus*) is an ice-associated mysticete that lives entirely in high-latitude circumpolar arctic seas. In Alaska, bowheads begin life in spring within the subzero (°C) waters of the ice-lead systems of the northern Bering, Chukchi and western Beaufort Seas. They may exceed 19 m in body length and 80 metric tons in body mass. The bowhead whale exhibits a number of superlatives among Cetacea, including the thickest blubber layer, the greatest known longevity of any mammal, the longest baleen, the lowest body core temperatures, and the largest head-to-body length ratio (Haldiman and Tarpley, 1993; George, 2009).

The Bering–Chukchi–Beaufort Seas (BCB) population of bowheads spends the summer months in the Chukchi and Beaufort Seas (Fig. 1). It is estimated that at the end of Yankee commercial whaling in 1910 (Bockstoce, 1986; Woodby and Botkin, 1993) the BCB bowhead whale population increased from a few thousand animals to nearly 17,000 individuals by 2011 (Givens et al., 2013). This increase is accredited to the cessation of commercial whaling, low natural mortality, a well-managed subsistence hunt, and relatively pristine habitat (George et al., 2004). Today, bowheads remain an important subsistence species for many coastal native communities in Russia, Alaska, and Canada.

Coincident with a growing population, the summer and fall habitats of the BCB stock have seen dramatic reductions in sea

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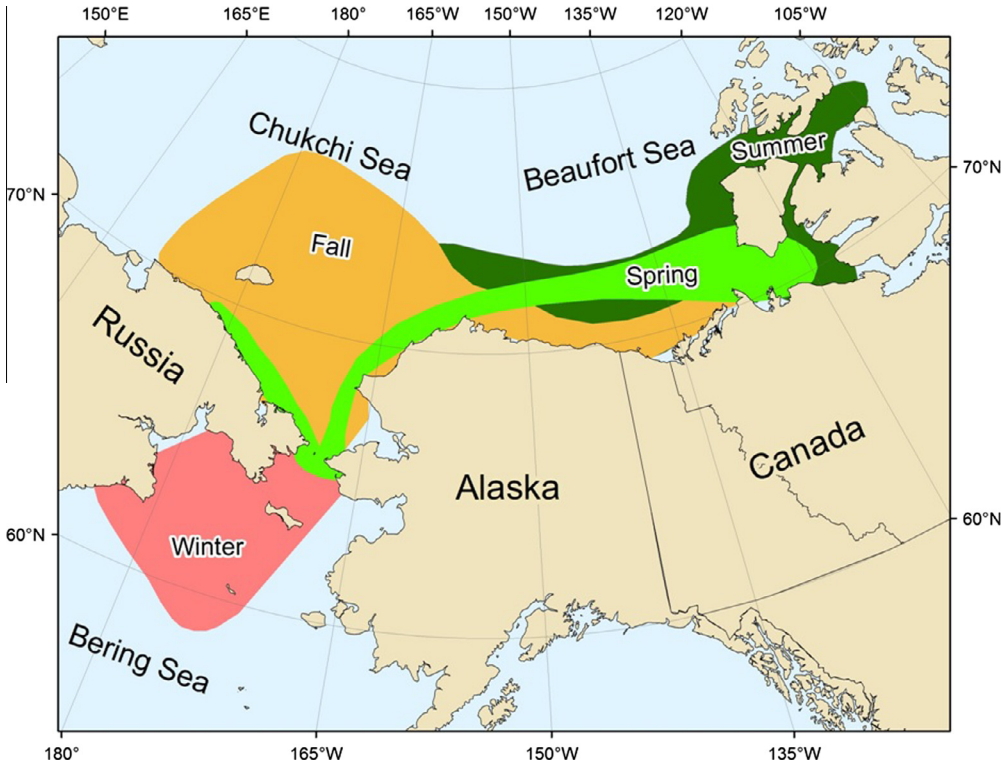

Fig. 1. Seasonal range map of the BCB bowhead whales based on satellite telemetry data (Quakenbush et al., 2012). Bowheads are also known to occur in regions outside these general boundaries.

ice. Since the start of the satellite record in 1979 Arctic summer sea ice extent has declined by 10.2% per decade (Comiso et al., 2008). The summer ice extent in September 2012—the lowest on record—was 49% below the 1979–2000 mean (NSIDC, 2012). Over this same time period, the Arctic melt season has also lengthened by about 20 days (Markus et al., 2009). These changes carry implications for both the pelagic and benthic components of the Arctic marine food web. Bowheads feed primarily on zooplankton (copepods and euphausiids), which are closely coupled to primary production. Thus, the bowhead whale serves as an important indicator species of Arctic environmental change (Moore and Laidre, 2006).

It is not entirely clear how loss of Arctic sea ice will impact bowhead whales over the long term, but there have been hypothesized trade-offs between loss of sea ice habitat and potential increases in food availability (Moore and Laidre, 2006; Laidre et al., 2008). Arctic summer sea ice retreat may drive increased phytoplankton blooms in the Arctic Ocean (see Arrigo and van Dijken, 2015), which may in turn promote greater zooplankton production. Ice algae and phytoplankton collectively provide an extended period of support to pelagic zooplankton, such as copepods and euphausids (Jin et al., 2012). Reductions in summer sea ice that lead to generally ice-free conditions over the continental shelves may also act to support zooplankton production by creating more opportunity for upwelling events (Pickart et al., 2009), which may bring nutrients to the euphotic zone to be used in primary production. This is especially important later in the summer after nutrients are depleted near the surface. In addition, these same continental-shelf upwelling events may act to advect and aggregate zooplankton, which may also benefit the feeding effectiveness of bowhead whales (Moore and Laidre, 2006). In general, for zooplankton communities to benefit from increased primary production, their grazing periods must match phytoplankton blooms (Kahru et al., 2011; Grebmeier et al., 2015). With increases in zooplankton production and aggregation, we may expect bowhead whales to feed more effectively during the summer and fall seasons in the Beaufort and Chukchi Seas and thus have improved body condition. In fact some preliminary analyses seemed to suggest a positive relationship between low sea ice densities and bowhead body condition (George et al., 2006).

The North Slope Borough Department of Wildlife Management, a municipal government in northern Alaska, has maintained an extensive dataset from postmortem examinations of bowhead whales harvested by Inupiat subsistence hunters. The dataset includes morphometric measurements from individual whales, which can be used to derive various metrics to monitor body condition changes across years, seasons, and age categories. This dataset is one of the most comprehensive datasets on Arctic cetacean body condition available. It also overlaps with a period of substantial environmental change in the Arctic making the data uniquely suited for analyses of the effects of sea ice loss on bowhead whales.

The objectives of this study were to: (1) define a body condition metric for harvested bowhead whales from the BCB population based on morphometric data; (2) quantify seasonal differences in body condition for different age classes; (3) examine trends in body condition over time (1989–2011, based on data availability); and (4) relate body condition trends to summer sea ice conditions, including open water fraction, duration of the melt season, and the onset of freeze-up, and the occurrence of upwelling-favorable winds.

2. Methods

2.1. Bowhead whale harvest data

We reviewed data from over 1200 individual harvested bowhead whales from the Alaskan communities of Kaktovik, Nuiqsut,