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Stable oxygen and hydrogen isotope analyses of bowhead whale baleen as biochemical recorders of migration and arctic environmental change

Pieter A.P. deHart [a,b,*], Candace M. Picco [b,c]

[a] Department of Biology, Virginia Military Institute, 24450, Lexington, VA, USA
[b] Institute of Marine Science, School of Fisheries & Ocean Sciences, University of Alaska Fairbanks, 99775, Fairbanks, AK, USA
[c] Nuu-chah-nulth Tribal Council, V0R 2Z0, Tofino, B.C., Canada

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Abstract

An analysis of the stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD) was used to examine the linkage between sea ice concentration and the migration of western arctic bowhead whales (*Balaena mysticetus*; WABW). We compared $\delta^{18}O$ and δD variability along the length of WABW baleen with isotopic values of zooplankton prey from different WABW habitat, with published $\delta^{13}C$ and $\delta^{15}N$ data, and with historical sea ice records. Zooplankton signatures varied widely ($\delta^{18}O = -13‰–56‰$; $\delta D = -220‰$ to $-75‰$), with regional separation between winter (Bering Sea) and summer (eastern Beaufort Sea) habitats of WABW observable in δD. The $\delta^{18}O$ and δD of WABW varied significantly along the length of baleen ($\delta^{18}O = 8–18‰$; $\delta D = -180$ to $-80‰$), confirming seasonal migration and reflecting distinct regional dietary variation in isotopes. WABW migration appears to have varied concomitant with temporal sea ice concentration (SIC) changes; in years with high SIC, the difference in δD of WABW baleen between seasonal habitats was significantly greater than low SIC periods. This work shows that SIC is not only a determinant of habitat accessibility for WABW, but baleen may also be a record of historical SIC and Arctic climate.

Keywords: Arctic Ocean; Sea ice; Bowhead whale; Stable isotopes; Climate change

1. Introduction

The bowhead whale (*Balaena mysticetus*) is a large baleen whale residing in circumpolar waters in the northern hemisphere. The largest management stock of this species is found in the areas of the Western Arctic (Western Arctic Bowhead Whales – WABW), extending from the Bering to the Chukchi and Beaufort seas (e.g., George et al., 1989). The latest population estimate for this particular stock is nearly 10,500 individuals, increasing at a rate of approximately 3.4% per year (Allen and Angliss, 2012). Associated with ice edges, the whales in this stock follow a somewhat predictable yearly migratory pattern (Fig. 1), traveling from the Bering Sea in the winter, through the Bering Strait and the northern Chukchi Sea, to the eastern Beaufort Sea and Mackenzie Bay for the warmer, more

* Corresponding author. Department of Biology, Virginia Military Institute, 24450, Lexington, VA, USA. Tel.: +1 540 464 7510.
E-mail address: dehartpa@vmi.edu (P.A.P. deHart).

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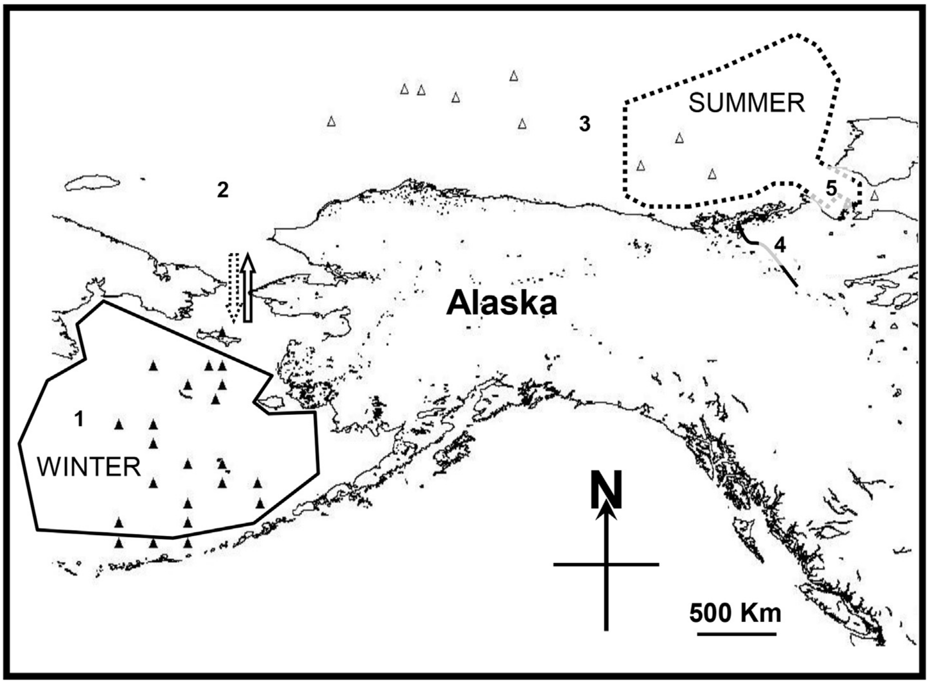

Fig. 1. General migratory endpoints of the western arctic bowhead whales, which migrate north and east from the Bering Sea (1) through the Chukchi Sea (2) and Beaufort Sea (3) to the outflow region of the Mackenzie River (4) and the Amundsen Gulf (5). Zooplankton sample locations are denoted from the Bering Sea (filled triangles) and Beaufort Sea (open triangles).

ice-free months (Moore and Reeves, 1993). The return trip, prompted by the expansion in sea ice extent during the fall and winter, takes the whales back along the coast of northern Alaska and perhaps the northeastern coast of Russia on their way back to the Bering Sea (Braham et al., 1980; Moore and Reeves, 1993; Schell et al., 1988). The specific grouping and sexual segregation of the WABW during their migration is relatively inconspicuous (Richardson et al., 1995). Unlike studies on populations of bowheads in the eastern Arctic (e.g., Matthews and Ferguson, 2015), most evidence suggests that WABWs are relatively solitary and driven by patterns of food availability, consuming prey throughout their migration (Allen and Angliss, 2012; Schell et al., 1989).

Along their migratory route, WABW feed on an array of zooplankton, with the majority of prey consisting of copepods and euphausiids (Lee et al., 2005; Lowry, 1993; Schell, 1992). These prey communities depend on the timing and productivity of primary producers along sea ice margins, prominent in the eastern Beaufort Sea and Mackenzie River outflow region (e.g., Iken et al., 2005) making these regions crucial to the survival of this species (Schell, 2000, 2001). Even though WABW have the ability to break through ice up to 60 cm thick (George et al., 1989; Haldiman and Tarpley, 1993), they still display behavioral characteristics consistent with the ability to detect and avoid old, thick ice areas (Moore and Reeves, 1993).

The sea ice throughout the Arctic and Bering Sea is undergoing rapid physical changes, influenced by a wide range of climate and atmospheric factors (Bond and Adams, 2002; Overland et al., 1999; Stabeno et al., 2001). Among these physical changes are temperature, precipitation, sea ice extent, and sea level rise (ACIA, 2004; Hunt et al., 2002; IPCC, 2007; Karl and Trenberth, 2003; Overland et al., 2004). In the Arctic and Sub-Arctic, the impacts of climate change also include measured reductions in ice density and extent (Parkinson et al., 1999; Wendler et al., 2010) and a decrease in ice thickness (Rothrock et al., 1999). The percentage of ocean covered with sea ice within a given pixel in a satellite image determines the sea ice concentration (SIC) (Thomas and Dieckmann, 2003). Research using this measurement has been incredibly insightful, and has both provided new views on ice conditions in marginal ice zones and been used to demonstrate the effects of physical forcing on the sea ice from seasonal to decadal timescales (Alexander and Niebauer, 1981; Clement et al., 2004; Neibauer et al., 1990; Picco, 2005). Sea ice concentration may be the