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Behavioral responses of beluga whales *(Delphinapterus leucas)* to environmental variation in an Arctic estuary

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A B S T R A C T

Some Arctic estuaries serve as substrate rubbing sites for beluga whales *(Delphinapterus leucas)* in the summer, representing a specialized resource for the species. Understanding how environmental variation affects the species' behavior is essential to management of these habitats in coming years as the climate changes. Spatiotemporal and environmental variables were recorded for behavioral observations, during which focal groups of whales in an estuary were video-recorded for enumeration and behavioral analysis. Multiple polynomial linear regression models were optimized to identify the effects of spatiotemporal and environmental conditions on group size, composition, and the frequency of behaviors being performed. Results suggest that belugas take advantage of environmental variation to express behaviors that 1) protect young, *e.g.,* bringing calves close to shore during cloudier days, obscuring visualization from terrestrial predators; 2) avoid predation, *e.g.,* rubbing against substrates at higher Beaufort sea states to obscure visualization, and resting during low tides while swimming on outgoing tides to avoid stranding; and 3) optimize bioenergetic resources, *e.g.,* swimming during lower Beaufort sea states and clearer days. Predictive models like the ones presented in this study can inform conservation management strategies as environmental conditions change in future years.

1. Introduction

Populations of species are the fundamental unit of conservation and the primary target of conservation management and policy directives (Van Dyke, 2008). Conservation efforts aimed at strategically selected populations can be powerful because of their inherent value to their environments (*e.g.,* keystone species), their occupation of environments in which other species are co-located, value as political motivators and natural resources to people, and as environmental monitoring tools (*e.g.,* sentinel species, Clemmons and Buchholz, 1997). When conservation efforts are directed at populations, knowledge of behavior is critical. For example, to inform the design of reserves (*e.g.,* marine protected areas, Clemmons and Buchholz, 1997), knowledge of control and ontogenetic mechanisms underlying migration, habitat selection, and breeding are necessary.

Variations in social behavior have been viewed as adaptations to variable environmental conditions. Social systems place constraints on which individuals can breed, and thereby shape population dynamics (Komdeur and Deerenberg, 1997). Understanding how environmental variation influences social behavior and structure, then, should be a key topic of consideration in conservation management.

1.1. *Arctic estuaries: a case for conservation management of the beluga whale*

The beluga whale (*Delphinapterus leucas*) is an abundant and widely-spread Arctic cetacean. Some populations remain relatively site-associated, while others migrate seasonally to take advantage of resources offered at various locales at different times of year (Kovacs and Lydersen, 2008). Summer occupation of Arctic estuaries is a cosmopolitan feature of migratory beluga whale populations. For example, in coastal Canada and Alaska, belugas have been observed occupying many estuaries during the summer season (Caron, 1987; Chmelnitsky, 2010; DeMaster et al., 2001; Finley et al., 1982; Frost et al., 1993; Harwood et al., 1996; Moore and DeMaster, 2000; Smith and Martin, 1994).

The reason for beluga presence in Arctic estuaries has been most thoroughly examined at Cunningham Inlet on the northern coast of

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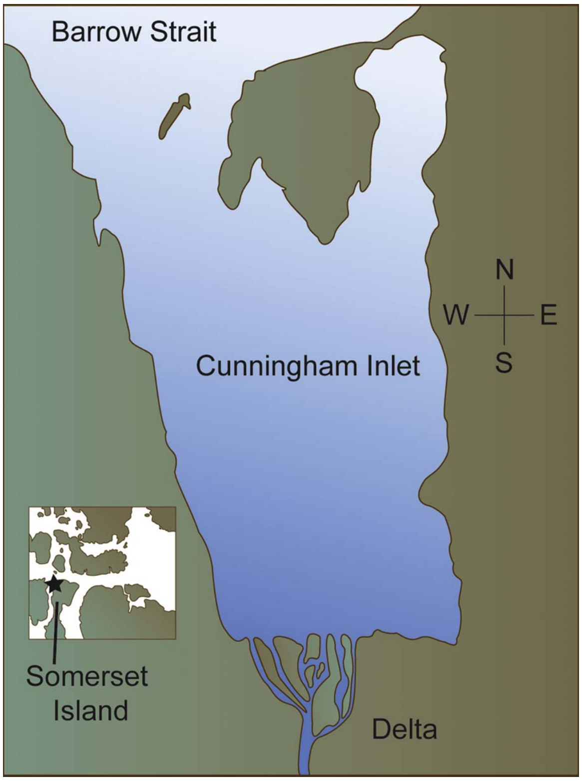

Fig. 1. Map of Cunningham Inlet. Inset: Eastern Canadian High Arctic archipelago, ★ = Cunningham Inlet..

Somerset Island in Nunavut, Canada by the eastern Canadian High Arctic stock during summer migrations (Richard et al., 2001, Fig. 1 inset). Whales comprising this stock use many of the warmer (~15 °C), low salinity bays and inlets fed by freshwater rivers and streams on the coasts of the Canadian Arctic Archipelago to hydrate, soften, and slough off old, hardened, keratinized winter skin in a molting process that is unique among cetaceans (Smith et al., 1992, 1994; St. Aubin et al., 1990).

Migration to and subsequent substrate rubbing behavior in bays and inlets is thus a specific, energy-intensive strategy in the life cycle of migratory beluga populations that is unique among cetaceans. Rubbing against substrates has been documented in 1 other cetacean (the orca, *Orcinus orca*), but without an associated migration dedicated for such a purpose (Ford, 1989; Thomas, 1970). The summer estuarine visit and substrate rubbing behavior of belugas are correlated with hormonal and epidermal changes associated with molting (St. Aubin and Geraci, 1989; St. Aubin et al., 1990). These behavioral and physiological processes are analogous to the molting process of birds, terrestrial mammals, and phocids. In those animals, the molt is energetically expensive but critical to endure in order to maintain healthy plumages or coats for effective flight (for birds), swimming (for aquatic animals), and thermoregulation (Otsuka et al., 2004).

1.2. The effects of environmental variation on marine mammal behavior and habitat use

Environmental variation affects the distribution and behaviors of marine mammals, including belugas. Observational and satellite tagging studies of belugas in Cunningham Inlet as well as other Arctic estuaries have demonstrated a strong correlation between beluga whale movement and tides (Caron, 1987; Ezer et al., 2008; Smith et al., 1994). Whales tend to swim upstream as tides rise and downstream as tides ebb. Rising tides afford whales with access to valuable resources upstream that are only temporarily available (*e.g.,* food, Ezer et al., 2008; substrate rubbing sites, Smith et al., 1994). However, upstream habitats can quickly turn dangerous upon ebbing tides, as sinuous channels can temporarily become land-locked, stranding whales and exposing them to subsequent predation risks (Smith, 1985; Smith et al., 1994).

Calm water, with low swell and wind stress, is beneficial to Northern and Southern Right whales (*Eubalaena glacialis* and *E. australis*, respectively); especially for weak-swimming neonatal calves (Thomas and Taber, 1984; Elwen and Best, 2004). These conditions afford improved survival and injury reduction, as well as bioenergetic savings, allowing for greater investment in growth (Elwen and Best, 2004). Humpback whales *(Megaptera novaeangliae)* increase surface activity in rougher seas (Scott and Winn, 1979; in Félix, 2004) and belugas do so in high winds (Caron, 1987). Félix (2004) posits that a rough sea may reduce water visibility and increase background noise, thus reducing the effectiveness of short-range communication (of humpback whales), forcing whales to increase noise production frequency through breaching or slapping to maintain some level of acoustic contact. Alternatively, humpback whales and belugas may simply need to surface more forcefully in rough seas in order to get and keep the blowhole above the water surface for respiration. In rough seas, Caron (1987) observed that belugas tended to occupy upstream waters more frequently than downstream waters, referencing the estuary as a shelter in rough seas.

Moreover, belugas were observed occupying upstream areas closer to putative substrate rubbing sites in greater number when waters were warmer (Caron, 1987). This phenomenon has been posited to confer a thermal energetic benefit by requiring a lower rate of energy expenditure to maintain a given epidermal temperature (Boily, 1995).

These qualities of the environment will shift over time. The coastal topography of Arctic estuaries is a critical factor to consider in the management of these habitats for belugas, which rely on them to rub against substrate and thus molt effectively (Smith, 1985; Smith et al., 1994). Sea level will likely continue to rise over time (Proshutinsky et al., 2001), impacting whales' access to upstream habitats, and changing the quality of those habitats (Brown et al., 2011; St-Hilaire-Gravel et al., 2012). Wind-mixing of estuarine waters and storms are both also predicted to increase in the future (Prowse et al., 2006); which may increase the energy expenditures of (particularly young) whales, detracting from growth, while also compromising the protection and resources that Arctic estuaries provide. Finally, Vavrus et al. (2009, 2011) predict increases in cloud cover over all seasons in the 21st century, with a spatial pattern of cloud gains that generally aligns with regions of large sea ice reductions. This trend may counteract thermal benefits provided by the sun during the molting process in Arctic estuaries.

1.3. Objectives

This study seeks to quantify if and how variation in spatiotemporal conditions *(whale distance)* and environmental conditions *(Beaufort sea state, percent clouds, tide, water level)* influences beluga whale group size, composition, and behaviors (aerial, floating, interactive, substrate rubbing, and swimming) in an Arctic estuary. Linking environmental variation to behavior is a necessary precursor to developing models to predict future population responses to environmental variation. Conservation management strategies are becoming increasingly important in this region in the face of increasing disturbances (*e.g.,* increased cloud cover, increased storminess, rising sea level), and their development will benefit from the knowledge of population responses to modeled environmental change, especially in critical habitats.

2. Materials and methods

2.1. Study site

Cunningham Inlet is a river-fed Arctic estuary on the northwestern