



Diving behavior of the Atlantic walrus in high Arctic Greenland and Canada

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ABSTRACT

Investigations of diving behavior of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the high Arctic Greenland and Canada are important for understanding behavioral adaptations and area utilization of this Arctic benthic feeder. Furthermore, such information along with estimations of annual consumption and carrying capacity of walruses are needed in management decisions of this utilized species. Satellite-linked transmitters deployed on 27 walruses from 2010 to 2013 provided data for investigations of diving behavior in three pre-defined main areas: NW Greenland, Smith Sound and NE Canada. Sub-areas within each main area were also compared. Depth of dives, dive rates, time at depth of dives, haul-out periods and vertical speeds were estimated. Majority of dives targeted depths from 10 to 100 m, which corresponds to the distribution of walrus preferred food items. Four dives to depths > 500 m occurred and are the deepest ever documented for a walrus. Dive rates and time at depth of dives were significantly different between sub-areas ($p < 0.0001$), whereas haul-out periods were not ($p = 0.072$). Mean vertical speeds to destination depths ranged from 1.0 m s^{-1} (95% CI: 0.8–1.2) to 1.8 m s^{-1} (95% CI: 1.0–2.6). Based on dive rates, time at depth, haul-out and percentage of feeding dives Alexandra Fjord and Princess Mary Bay in NE Canada and Carey Island in NW Greenland were identified as the most important areas for walrus feeding during summer. Walrus predation on the standing bivalve biomass in NW Greenland (within 5–100 m of depth) was estimated to 3.2% annually based on assessments of mean biomass of walrus preferred prey items. From a simple relationship between available shallow water habitat, current population size ($n = 2544$) and walrus pre-exploitation population sizes it is furthermore proposed that the carrying capacity in the Smith Sound region does not exceed 5000 walruses.

1. Introduction

The warming of the Arctic and changes in Arctic marine biota in response to climate change are well documented (Wassmann et al., 2011). Atlantic walruses (*Odobenus rosmarus rosmarus*) are benthic feeders. They occur north of the Arctic Circle for most of the year and depend on the Arctic ecosystem for all aspects of life (Laidre et al., 2008). Understanding diving behavior and area utilization of this Arctic marine mammal is essential for assessing how vital behaviors change when animals are exposed to environmental stressors and to ensure correct management decisions in the light of a changing environment.

Smith Sound, located between Northwest (NW) Greenland and the Canadian high Arctic, attracts large numbers of marine top-predators most of which are only in the area during the open water season where they primarily feed in the pelagic part of the food web (Heide-Jørgensen et al., 2013). The Atlantic walrus is one of few marine mammals that remain when a recurring polynya – the North Water –

forms during winter in Smith Sound. During winter and spring, variable and usually small amounts of, open water can be found in the coastal areas adjacent to the North Water. In contrast to the summer visitors, the walruses depend on benthic prey where bivalve molluscs constitute most of their diet (Vibe, 1950). The walruses feed mainly in shallow waters (< 100 m) where they can reach the seabed and prey on molluscs (Fay and Burns, 1988; Jay et al., 2001). However, shallow water habitats, where the majority of bivalves are found, constitute only a minor part of the Arctic in this region. A recent study (Lowther et al., 2015) documented that walruses near Svalbard are capable of diving to great depths (461.9 m) and in theory can stay submerged for extended periods of time (max. 57 min) (Schreer and Kovacs, 1997). In light of the environmental changes occurring rapidly in Arctic regions and new information on walrus diving capacity it seems prudent to assess the walruses utilization of this high Arctic region through documentation of diving habits.

Vibe (1950) described walrus foraging banks in NW Greenland

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ranging from the south-eastern part of Smith Sound to Kane Basin that constitute the northern boundary of walrus distribution. Except for the work of Vibe, there is little information on benthic communities and walrus consumption rates in this region. In the Bering and Chukchi seas (i.e. Beringia), Pacific walruses (*O. r. divergens*) annually consume an estimated 3 million metric tons of benthic biomass (Ray et al., 2006). Ray et al. (2006) found that the annual to long-term bioturbation from walrus feeding activity resulted in significant, large-scale changes in sediment and biological community structure. Furthermore, nutrients locked in the sediment were redistributed to the water column by about two orders of magnitude over large areas. Walruses have also been observed to eat seals and birds in addition to benthic prey (Lowry and Fay, 1984; Fay and Sease, 1990; Fox et al., 2010; Mallory et al., 2004; Lovvorn et al., 2010) but only a few observations of seal remains in the stomachs of walruses from the Smith Sound have been documented (Vibe, 1950).

The walruses in the Smith Sound region (defined as Smith Sound, coast and fjord systems in NW Greenland and coast, bays and inlets in eastern Canadian High Arctic) belong to the Baffin Bay walrus stock (Stewart, 2008). They stay from October to June in NW Greenland. In early to mid June, they cross Smith Sound and stay in shallow bays and inlets of the eastern part of Ellesmere Island, Jones Sound and south of Devon Island during summer (Heide-Jørgensen et al., 2017). Heide-Jørgensen et al. (2017) found that most frequently used summering areas were the Alexandra Fjord/Buchanan Bay/Flagler Bay area, Talbot Inlet and Craig Harbour along the coast of Ellesmere Island.

This study investigated the diving behavior of walruses of the Baffin Bay stock by using satellite transmitters specialized to provide positions and data on diving. Study objectives were to answer the following questions: 1) what are the characteristics of the diving behavior of walruses in the Smith Sound region, and 2) can important feeding areas and consumption rates of walrus in the Smith Sound region be identified using available data.

2. Materials and methods

2.1. Definition of study areas

Smith Sound is located in northern Baffin Bay between NW Greenland and the eastern part of the Canadian high Arctic (76°N to 79°N and 70°W to 80°W). Walruses cross Smith Sound from NW Greenland in June to summer in the eastern part of the Canadian high Arctic (Heide-Jørgensen et al., 2017). They return to Greenland in October. Based on this seasonal distribution three main areas of walrus occupancy were defined (Fig. 1): NW Greenland, including the coast, fjords and inlets, up to 30 km from the coastline (approximately 76°N to 79°N and 69°W to 73°W); the eastern part of the Canadian high Arctic, called NE Canada throughout, including the east coast, fjords and inlets of Ellesmere Island up to 30 km off the coast, Kane Basin, Pim Island, Jones Sound, Coburg Island and coastal areas south and east of Devon Island (approximately 74°N to 80°N and 75°W to 92°W); and Smith Sound defined as the deep offshore area between NW Greenland and NE Canada, not overlapping the former two main areas. The three main areas were further divided into several sub-areas and termed the Smith Sound region. The sub-area of Alexandra Fjord includes fjords on Ellesmere Island between 78.76°N and 79.22°N.

2.2. Field operations

During May–June 2010–2013 and 2015, 51 walruses were instrumented with satellite-linked transmitters in NW Greenland. Walruses were located and tagged at four different locations (Etah, Murchison Sound, south of Kiatak, and in Wolstenholme Fjord) (Fig. 1). Description of the tags and deployments methods is provided in Heide-Jørgensen et al. (2017). Of the 51 tags 27 (deployed from 2010 to 2013) were of the type Mk10 that in addition to positions also provided

summarized data on the diving behavior of the walruses. Of the 27 Mk10 tags, 26 tags transmitted data and 21 provided diving data in several consecutive days. The 21 tags were deployed on 13 females, 3 males and 5 walruses with no information on sex. The tags were programmed to transmit at different intervals during the five years with deployments. In 2010–2011 the tags were programmed to transmit every day between 8:00 and 20:00 local time in June and every fourth day the rest of the year. This setting failed in July 2010 and no positions were obtained for that month. The same setting was used in 2012 except that the tags were allowed to transmit every day in August. In 2013 and 2015 all tags were programmed to transmit every fourth day independent of month. The sex of tagged walruses was determined from sexually dimorphic features (Fay, 1982) or the presence of a calf close to an adult female. If sex could not be determined using these methods, the sex of the animal was classified as unknown.

2.3. Area and dive data

Positions of the walruses were obtained from the Argos satellite data processing system with Kalman filtering algorithm, and the accuracy of positions was classified by Argos location codes (LC) 3–0, A and B (CLS America, 2007). More than 70% of the positions obtained ($n = 37,000$) from the walruses were of low or uncertain positional accuracy (quality 0, A or B). Filtering of positions and tracks of the walruses are presented in Heide-Jørgensen et al. (2017).

The Mk10 tags provided data on the number and depth of dives (DOD) and the time-at-depth (TAD, in %) in predetermined bins. The setup of the bins for TAD was 0, 0–< 2, 2–< 20, 20–< 50, 50–< 100, 100–< 150, 150–< 200, 200–< 300, 300–< 400, 400–< 500, 500–< 600 m and the same for DOD except that the first bin was 0–10 m, second bin 10–20 m and the rest as TAD. Data on DOD and TAD were collected in four 6-h periods across each day and summarized into histograms. Only 6-h periods with information on both DOD and TAD were used in the analysis. Intervals between surfacing's were not considered dives unless a depth of > 2 m was recorded. Time spent within a depth category with a duration of < 1 s may have been missed because of the short temporal resolution. Data on the maximum depth (m) of dives (MAX dives) within 24 h were also collected. Dive data were transmitted in segments when the walruses surfaced, and were re-assembled using Wildlife Computers software packages (SATPAK). MAX dives were included on every 20th transmission and the temporal coverage is therefore much below the high priority transmissions of DOD and TAD with more missing data for the MAX dataset than for the other datasets.

2.4. Vertical speeds ($m s^{-1}$)

The rates of ascent and descent of dives could occasionally be calculated if the deepest destination depth bin was isolated from the previous transit bins by one or more bin(s) without dives (Heide-Jørgensen and Dietz, 1995). The isolated destination depth bin provided the number of dives that went through the transit bins and the transit bins provided the incremented amount of time spent passing through the transit bins. Vertical speeds to destination depths bin ($\bar{S}_j$ where j = depth bin) were calculated based on a model developed in Heide-Jørgensen et al. (1998):

$$\text{Vertical speed } (\bar{S}_j) = N_j * D / (\sum TAD / 2) \quad (1)$$

where N_j is the number of dives to an isolated destination depth bin, D is the vertical distance (in m) across the transit depth bins to the isolated destination depth, and $\sum TAD$ is the sum of time-at-depth measurements (in s) through the transit depth bins. The $\sum TAD$ is divided by two because it includes both ascent and descent times. Average vertical speeds ($\bar{S}_j$) were calculated for all dives to each isolated depth bin for walruses tagged between 2010 and 2013. The vertical speeds were used

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