

Behavioral ecology of narwhals in a changing Arctic

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Award Number: N000141110201

LONG-TERM GOALS

Our primary goal is to understand baseline narwhal (*Monodon monoceros*) behavioral ecology in the pack ice of Baffin Bay. We will collect data on the species' acoustic, movement, and diving ecology in the offshore pack ice of Baffin Bay over a 4 year long research program with three ecological focus areas (acoustic ecology, sea ice ecology, and foraging ecology). Our longitudinal and cross-population analyses will use a suite of ecological modeling approaches over a >2 decade period that encompass a period of sea ice decline and increased anthropogenic activities in West Greenland (1993-present).

OBJECTIVES

Our objectives are to answer the following science questions:

1. Acoustic ecology: What are baseline characteristics of the acoustic repertoire of narwhals in the offshore Baffin Bay pack ice (depth-specific high frequency calls, echolocation clicks, and buzzes during foraging dives)? What is the ecophysiological and communicative function of various click types of narwhals in this high-latitude offshore ice covered habitat? How might acoustic communication and foraging ecology be impacted by increasing anthropogenic activities in Baffin Bay (increasing shipping, future transit through the NW Passage, seismic exploration, increasing tourism)?
2. Sea ice habitat selection: How are narwhals' movements in Baffin Bay related to sea ice concentration, distance to the sea ice edge, location of glacial outlets and behavior of glaciers in Greenland, and the timing of sea ice break-up (as measured by the date when sea ice concentration drops below some threshold)? How have these relationships changed over the past two decades of sea ice loss? Are there population-level differences in sea ice habitat selection?
3. Foraging ecology: Do the winter home ranges of narwhals overlap with high densities of Greenland halibut and are there habitat parameters that quantitatively describe the overlap of this predator and its prey? What is the potential predation impact on the offshore Greenland halibut stock?
4. Predation: What are the spatial and temporal trends in the occurrence of killer whales in West Greenland? Given the loss of annual sea ice and purported increase in killer whales in the Canadian Arctic, do killer whale catch and observation data from West Greenland follow this trend and have narwhals been exposed to increasing risk of predation?

APPROACH

Pack ice field work

We designed and built an acoustic recording station set up at leads in pack ice within high-density offshore narwhal wintering grounds. This station records depth-specific high frequency calls, echolocation clicks, and buzzes on narwhal foraging dives. We took two approaches to collecting acoustic data from narwhals. First, we deployed a 15Hz-480kHz Reson hydrophone with pre-amplifier and recording using a National Instruments sound card with a sample rate of 500 kHz. Recent studies using wide-band acoustic sampling in the Northeast Atlantic have documented killer whales (*Orcinus orca*), the largest delphinid, produce whistles with the highest fundamental frequencies ever reported. These ultrasonic whistles may also occur in medium sized odontocetes (i.e. narwhals) but has never been studied. The use of this first approach should ensure that the sampling scheme used to collect baseline data on narwhal acoustics in the pack ice is not inherently constrained by *a priori* sampling decisions (where insufficient sampling frequency results in portions of whistles being missed). Second, we utilized a custom made 16 channel vertical array (with a laptop and pre-amplifier inside an insulated aluminium box) as a stand-alone system recording between the surface and 25 m. This provides the foundation to quantify details in narwhal echolocation behavior. We conducted the field work for this project in the pack ice in 2012 and 2013 in Greenland. All personnel and equipment were deployed and retrieved from the ice using an Air Greenland helicopter (AS350). The helicopter spotted groups of narwhals and identified locations for deploying hydrophones.

Analysis and habitat modeling

We are currently conducting the analysis and publishing our acoustic data. This is being done in collaboration with Jens Koblitz (post doc at German Oceanographic Museum, who designed the vertical array). We have completed the analyses and are in the process of writing our second manuscript. We are also using an extensive data analysis of over 18 years of satellite tracking and dive data (1993-2009) from five different narwhal subpopulations (Dietz and Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2002, Heide-Jørgensen et al. 2003, Dietz et al. 2008) to look at movements and sea ice associations. The satellite tracking database includes tracking data from n=79 individual narwhals tagged in Melville Bay (West Greenland), Somerset Island (Canada), Eclipse Sound (Canada), and Admiralty Inlet (Canada), and Uummannaq (West Greenland). We are using the narwhal satellite tracking data to identify individual trajectories, focal areas, and population-level home ranges. We examine speed, dispersal, and movements under different ice regimes and quantify fine scale winter habitat selection/sea ice characteristics within focal areas by extracting a suite of habitat variables and remotely-sensed data on sea ice conditions. Sea ice concentration data are used to construct resource selection, to compute long-term trends in sea ice parameters in specific regions of Baffin Bay, and to compute sea ice parameters along the trajectories followed by narwhals. Our primary data source for sea ice is the satellite passive microwave data from SMMR and SSM/I (1979-present) (25-km pixel size). AMSR-E data will be used to compute specific parameters in the post-2002 period at a higher resolution (6.25 km pixel size).

WORK COMPLETED

Our past year (2015) has been spent on analysis of data, including the analysis of narwhal telemetry and analysis the acoustic data. We published our first manuscript in *Aquatic Mammals*, are preparing the second one documenting ultra-high frequency clicks of narwhals for peer review to be submitted to PloS. We are also part of an invited workshop to present the results of the narwhal movements in Baffin Bay glacier fronts at the American Geophysical Union (2015) and it will be part of a special issue in *Biology Letters* submitted in February 2016. Our second acoustic paper on data from the 16 channel vertical array contains our most relevant and novel results, documenting the most directional clicks of any marine mammal. We have also compiled all available data on killer whale occurrence, dedicated and opportunistic sightings, and harvest records in West Greenland and Baffin Bay since 1970s. We are in the process of examining trends in the occurrence of narwhal predators, as well as spatial and temporal overlap based on the spatial models of area use. These records are kept by the Hunting Department of the Government of Greenland and for each catch record of killer whales details are recorded by hunters (submitted in catch reporting annually) and are available to our study through our collaboration with the Greenland Institute of Natural Resources.

RESULTS

Our primary analytical accomplishments this year include two published papers (Rasmussen et al. and Laidre et al., see pubs). The first paper deals with the high frequency broad-band clicks recorded from narwhals in April 2012 and 2013. Recordings were conducted using a single Reson hydrophone with a sample rate of 500 kHz and an Acousonde™ 3B with a sample rate of 250 kHz. The energy in the high frequency narwhal clicks extended up to 200 kHz. Buzzes with click rates up to 300 clicks /sec were also recorded, however no whistles were obtained. Our paper discuss how this is the first time the whole bandwidth of narwhal echolocation clicks has reported, and the first case where buzzes have

been recorded from narwhals at their wintering ground. These data may have implications for conservation and management considering ongoing and expected significant increases in anthropogenic sound (e.g., seismic exploration, shipping) in the Arctic. The second paper is a broad review of Arctic marine mammal ecological vulnerability, and the results from this directed field work informed the conservation perspectives outline in that paper relating to narwhals. Our upcoming papers are as follows: an acoustic paper which will be submitted in the next few months that quantifying details of narwhal echolocation behavior. Using the recording obtained with the 16 channel vertical hydrophone array we determined swim speed and ascent rates, measured the intensity (the source level) of narwhal echolocation clicks, measured the width of narwhal echolocation beam and computed the volume of water body covered with every click, and investigated the scanning behavior, i.e. changes of the acoustic gaze while ascending to the surface in order to breathe.

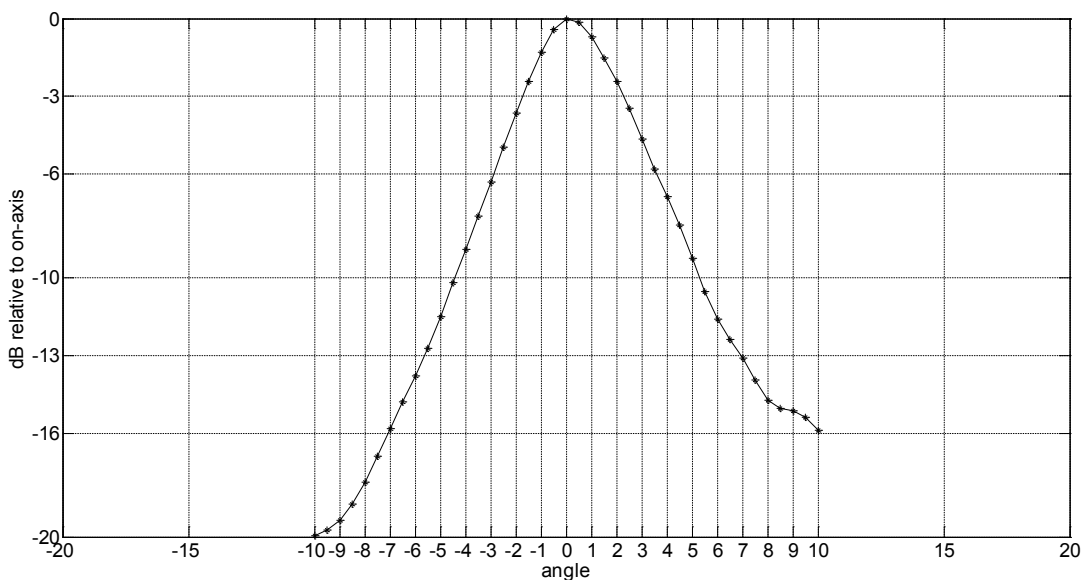


Figure 1. Average interpolated beam pattern based on 70 clicks emitted by a single narwhal within 20 seconds. This figure shows the highest directionality for any odontocete recorded to date

Our telemetry analyses to be submitted this year cover the movements of narwhals tagged with satellite transmitters from Admiralty Inlet, Baffin Island, Canada. We compared interannual migration routes and winter ranges across years with contrasting sea ice conditions. There was a high degree of inter-individual variability in the date whales departed from the summering areas. The wintering areas ranged from 33,000 to >120,000 km². No significant differences in mean latitude during the winter period were found across the three years, however median winter velocity (km/day) was significantly different across years ($p=0.002$), with the lowest velocity for the years whales remained in Baffin Bay and the highest velocities in years whales also used Davis Strait. These differences in range and velocity coincided with large variability in annual sea ice conditions in Baffin Bay. Narwhals ranged most widely and had the highest winter velocities in years with the most dense sea ice cover, suggesting heavy ice years requires whales to conduct compensatory movements to keep up with moving leads and cracks. On the contrary, low sea ice cover on the wintering grounds resulted in

whales remaining stationary over their preferred foraging ground for longer periods and lower daily velocities without requiring large movements.

In addition we have nearly completed the analysis of glacier habitat selection. This includes information on the ice front location (at each of 25 glaciers in the range of narwhals in summer in West Greenland) and discharge rates and advancement or recession trends in glacial ice drainage sites (Moon and Joughin 2008). We use a state-space modeling approach to develop proximity matrices for narwhals at glacial fronts at a range of distance (3-10 km). We modeled the occurrence of narwhals as a function of glacier covariates, including glacier velocity, direction (retreat or advance), sediment outflow and depth in front of the glacial moraine. This will be presented in December 2015 at AGU and will be part of a special edition of *Biology Letters*, submitted in February 2016.

IMPACT/APPLICATIONS

1. New baseline information on the ecology of narwhals in the pack ice. This study will provide the first critical baseline data on acoustic foraging ecology of narwhals in an area rapidly being altered by increases in shipping, seismic exploration, and sea ice loss. We anticipate our results will be of broad interest to managers for predicting impacts of anthropogenic activities on this vulnerable species. We utilize a combination of new data collected from field studies with a long-term historical archive combined with remotely-sensed imagery to provide new information on narwhal ecology in a changing Arctic.

Potential future impact for Science and/or Systems Applications

2. New techniques for ecological studies of whales in dense sea ice. Our study develops technical and methodological advances for acoustics work from leads and cracks in the pack ice Arctic. Design and deployment of portable heated systems that can be deployed from a helicopter will advance possibilities

RELATED PROJECTS

None.

PUBLICATIONS

Rasmussen, M., J. Koblitz, and K. L. Laidre. 2015. Buzzes and rather high frequency clicks recorded from narwhals (*Monodon monoceros*) at their wintering feeding ground. *Aquatic Mammals* 41(3): 256-264.

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