Behavioral Ecology of Narwhals in a Changing Arctic

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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).

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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 utlilized 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 foundationto 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

be 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 of the acoustic data. This is being done in collaboration with Jens Koblitz (German Oceanographic Museum, who designed the vertical array). He will will work as a post-doc on the project in 2014. 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 s 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). We will also use AMSR-derived daily sea ice velocity fields in Baffin Bay (supplied by Dr. Ron Kwok at the Jet Propulsion Laboratory) and SSM/I-derived sea ice velocity fields (from NSIDC in Boulder) to characterize the sea ice velocity and its variability.

WORK COMPLETED

Analysis work. Our past year (2014) has been spent on analysis of data, including the analysis of narwhal telemetry and analysis the acoustic data (see below). We have submitted one manuscript relating winter movements in Baffin Bay to fluctuations in sea ice cover and submitted a second manuscript documenting ultra-high frequency clicks of narwhals for peer review. In addition, we have started a new analysis examining the habitat selection by narwhals in glacier fronts in Greenland. We expect to have a paper on these glacial habitat associations submitted this year. In addition, we will have a second acoustic paper on data from the 16 channel vertical array submitted once the analysis is completed this upcoming year by a post doc. 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 submitted papers. 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 new analysis we are working on this year deals with quantifying details of narwhal echolocation behavior. Using the recording obtained with the 16 channgel vertical hydrophone array we will: 1) Determine swim speed and ascent rates, 2) Measure the intensity (the source level) of narwhal echolocation clicks, 3) Measure the width of narwhal echolocation beam and hence compute the volume of water body covered with every click, and 4) Investigate the scanning behavior, i.e. changes of the acoustic gaze while ascending to the surface in order to breathe.

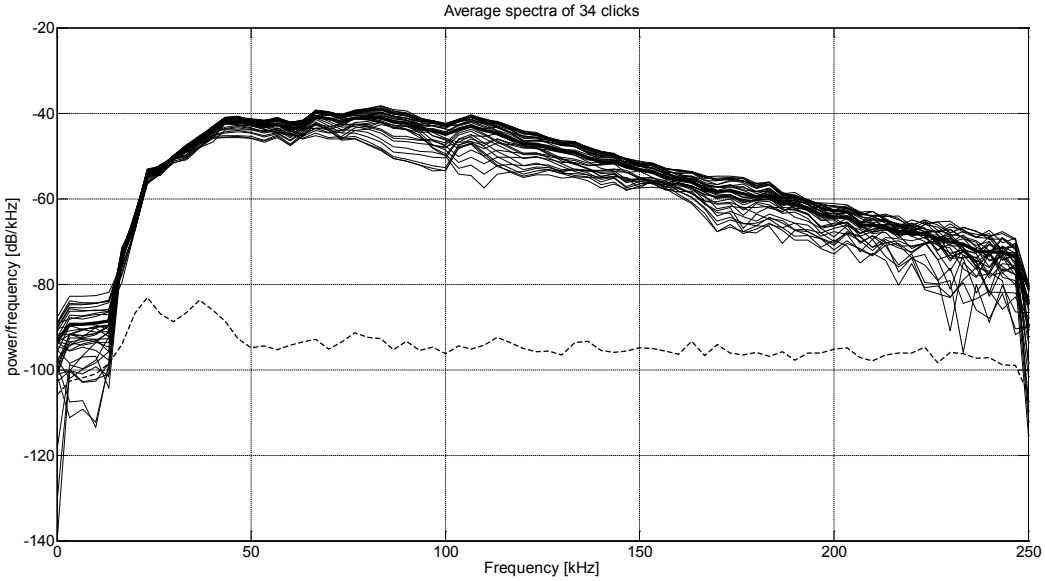

Figure 1. Average spectra of 34 narwhal echolocation clicks (solid black line) and spectra of all 34 clicks (fine lines). Spectra of noise floor plotted in dashed line. The peak frequency of the average spectra is 67 kHz, at 200 kHz the power is reduced by 23 dB, however well above the noise floor.

The second paper deals with 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 km^2. 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.

Finally, the analysis of glacier habitat selection is in progress. 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 plan to model 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.

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

1. 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

Gregr, E. J., M. F. Baumgartner, K. L. Laidre, D. M. Palacios, D. M. 2013. Marine mammal habitat models come of age: the emergence of ecological and management relevance. Endangered Species Research 22:205-212.

Palacios, D. M., M. F. Baumgartner, K. L. Laidre, and E. J. Gregr. 2013. The challenge ahead: integrating environmentally and behaviorally mediated ecological processes in marine mammal distribution models. Endangered Species Research 22:191-203.