Chapter 88
Measuring Hearing in Wild Beluga Whales

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Abstract We measured the hearing abilities of seven wild beluga whales (*Delphinapterus leucas*) during a collection-and-release experiment in Bristol Bay, AK. Here we summarize the methods and initial data from one animal and discuss the implications of this experiment. Audiograms were collected from 4 to 150 kHz. The animal with the lowest threshold heard best at 80 kHz and demonstrated overall good hearing from 22 to 110 kHz. The robustness of the methodology and data suggest that the auditory evoked potential audiograms can be incorporated into future collection-and-release health assessments. Such methods may provide high-quality results for multiple animals, facilitating population-level audiograms and hearing measures in new species.

Keywords Anthropogenic noise • Sensory • Marine mammal • Cetacean • Odontocete • Arctic

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1 Introduction

Hearing is the primary sensory modality for odontocete marine mammals. They are generally considered to have sensitive hearing and may detect a broad range of frequencies. Relying on hearing can be particularly adaptive in the marine environment where light and other cues are often limited and natural sounds are frequently abundant. Yet these sensitive auditory abilities may also be easily impacted by anthropogenic noise.

Human use of the Earth's oceans has steadily increased over the last century, resulting in an increase in anthropogenically produced noise (e.g., National Academy of Sciences 2003). The Arctic is no exception to this increase (Blackwell and Greene Jr 2003). Reductions in polar sea ice and the opening of the Northwest Passage presumably will open up habitats for many top predators. Yet this decrease in sea ice provides greater human access to a high-latitude environment, and such a change is poised to transform a relatively pristine environment into one saturated with human activities and associated noise. Sources are varied and include naval exercises, boundary definitions, shipping/movement along Alaska's North Slope, seismic resources exploration, and the construction of an infrastructure needed to support it (Wang and Overland 2009; Titley and St. John 2010). These changes encompass the habitats of *Delphinapterus leucas* (beluga whales) and other top predators. Despite this obvious overlap of human-natural interests, there is a poor understanding of influences of these sound-associated changes. To estimate the impacts of this noise, it is crucial to evaluate the natural hearing abilities and the variation with marine mammal populations.

Yet a primary challenge is that audiograms of odontocete marine mammals have most often been estimated from stranded animals or nonwild individuals (for a review, see Mooney et al. 2012). In many instances, these records have produced valuable data that are otherwise unavailable. For example, hearing in several stranded beaked whale species have helped define what these sound-sensitive animals hear (Finneran et al. 2009; Pacini et al. 2011). The audiogram of a stranded infant Risso's dolphin helped redefine what the species actually detects (Nachtigall et al. 2005). Work with trained odontocetes provides scientific data that are likely unique to those settings and can address how animals hear or how they may be protected from anthropogenic noise (Nachtigall and Supin 2008). Yet, in many instances, health-compromised stranded animals may not have normal auditory abilities and thus are not necessarily representative of wild populations. Furthermore, without baselines for wild individuals, it is difficult to put differences and results of nonwild individuals in a relative context. Clearly, there is value in increasing the number of animals within a species measured for hearing capabilities whenever possible.

Here we describe the methods and initial results for measuring the hearing of wild *D. leucas* (Castellote et al. 2014). The goal of this study was to determine hearing sensitivity in wild Bristol Bay *D. leucas* during a planned collection-and-release operation. Monitoring of *D. leucas* has been recommended in recent years because this species is likely to be negatively impacted by climate change and because such a broadly dispersed, high-trophic feeder can serve as an effective sentinel of the ecosystem(s) in which it lives (Moore 2008; Moore and Huntington 2008; Simpkins et al. 2009). Because noise may impact *D. leucas* in a variety of ways, it is essential to determine what these animals hear.

In view of the expected changes in the Arctic acoustic environment, expanding our knowledge of *D. leucas* hearing is of central importance for an appropriate conservation management framework. One of the five distinct stocks of *D. leucas* whales that are currently recognized in US waters, the Cook Inlet *D. leucas* population is endangered and efforts for its recovery to date have not been successful. The impact of anthropogenic noise has been identified as a serious threat, potentially impeding recovery (NMFS 2008). On the contrary, the Bristol Bay *D. leucas* population is increasing and is considered to be a healthy population (NMFS 2008). The acoustic environment in Bristol Bay is different; many of the chronic anthropogenic sources typically found in the Cook Inlet *D. leucas* habitat are essentially absent or seasonally present at lower intensities in the Bristol Bay habitat. This suggests that Bristol Bay *D. leucas* are a valuable asset to evaluate baseline hearing and health measures for comparison to affected populations such as Cook Inlet *D. leucas*.

2 Temporary Collection of Beluga Whales and Hearing Test Methods

This study was conducted in September 2012 in Bristol Bay, AK. The audiograms were measured during an overall health assessment study that required the collection and release of *D. leucas*. Audiograms were obtained from seven of seven belugas tested. The procedures were similar to those followed by Ferrero et al. (2000) and were conducted under National Marine Fisheries Service Marine Mammal Research Permit No. 14245 and approved by the necessary Institutional Animal Care and Use Committees. The full results are published elsewhere (Castellote et al. 2014); here we provide a summary of the methods and preliminary results.

Bristol Bay is a generally shallow, muddy-bottomed estuary system that supports a population of *D. leucas*. Using three 3.5-m aluminum skiffs and one soft-bodied inflatable boat, we searched for an adult beluga. When a suitable animal was spotted (Fig. 88.1), one of the skiffs would follow and gradually approach the whale to encourage it to swim into shallow water (<2 m). From one of the boats, a 125-m-long by 4-m-deep net made of 0.3-m braided square mesh was deployed around the whale. Once the deployment boat and net encircled the whale, the inflatable boat approached the outside of the net and three handlers placed a soft tail rope around the whale's peduncle. The rope's other end was fixed to the inflatable boat to secure the whale. The large net was gradually recalled while a "belly-band" stretcher was placed under the *D. leucas*. Handholds in this stretcher facilitated adjusting the whale's position as the water depth changed with the tide. The animal was then positioned parallel to the small inflatable boat. The *D. leucas*'s head typically rested on or was just above the soft mud bottom, keeping the lower jaw and primary hearing pathways below the water surface. The animal's blowhole was generally above the surface. This setup

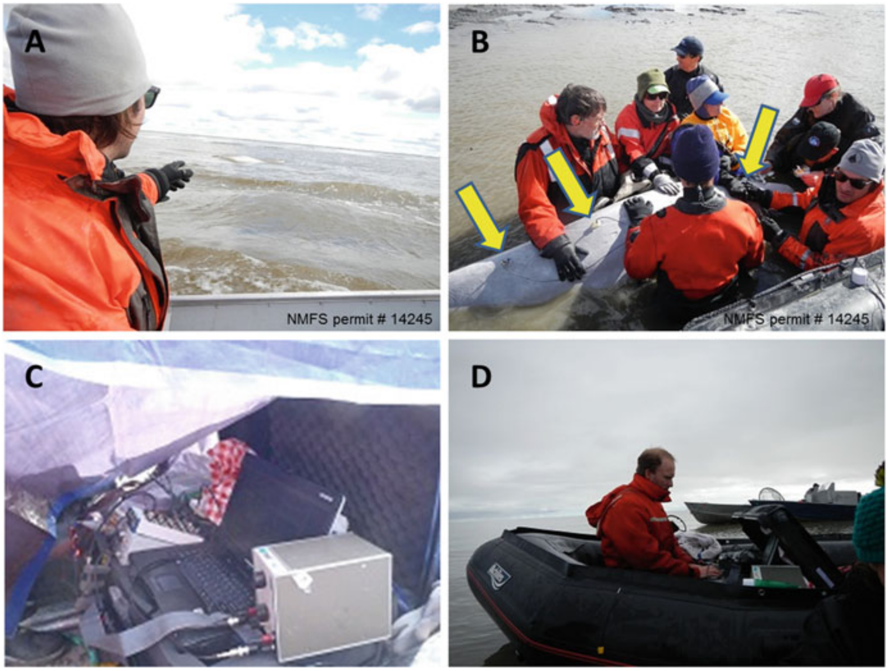

Fig. 88.1 (**a**) Spotting a *Delphinapterus leucas* from the aluminum skiff. (**b**) Auditory evoked potential (AEP) audiogram setup. *Arrows*, recording, reference, and ground electrodes from posterior to anterior (*right* to *left*). A measure of breath is also being taken concurrently. (**c**) AEP system in its case. (**d**) AEP system in the soft inflatable boat during data recording

was consistent for all animals, except one for which the water level was too low and this test was conducted partly out of the water. Animals were maintained in this position for the audiogram and health exam. The auditory evoked potential test equipment was outfitted in a ruggedized case; both it and the operator sat in the small inflatable boat beside the *D. leucas* during the hearing tests (Fig. 88.1).

Hearing was tested using auditory evoked potential methodology following methods generally described elsewhere (e.g., Nachtigall et al. 2007). Sound stimuli, generated in a custom program, consisted of amplitude-modulated tone-pip stimuli, 20 ms in duration, and presented at a modulation rate of 1 kHz and 20 s^{-1}. Tones were presented through a suction-cup transducer attached to the tip of the lower jaw. Evoked potential data were recorded for 30 ms, starting concurrently with tone stimuli. Responses were bandpass filtered from 300 to 3,000 Hz. Five hundred sweeps were averaged per single record by the custom program and stored on a semirugged laptop computer. Thresholds were determined taking the fast Fourier transform-based frequency spectra of each envelope following responses (EFRs), and plotting those microvolt peaks relative to their respective sound pressure. A best-fit regression line was fit to these peak data points. A sound level value where the regression line theoretically generated a 0-μV response was taken as the threshold for that frequency.

3 Results and Discussion

Audiograms were successfully collected from all seven adult *D. leucas* whales temporarily collected and tested. Evoked response waveforms and EFRs were generally easily identifiable and distinct from the background electrophysiological noise. The inset in Fig. 88.2 shows an EFR that was recorded using stimuli of ~20 dB around the hearing threshold of 32 kHz. Such a measurement would take ~30 s to collect. Thus, overall thresholds at a particular frequency were obtained in 3–5 min. This relatively rapid threshold measurement facilitated collecting multiple thresholds per animal but also minimizing the "with-animal" time. For example, the audiogram of animal 7 consisted of 12 frequencies tested. Two of these (4 and 150 kHz) did not induce measureable AEPs. The entire dataset was collected in 55 min, which included multiple breaks for other measurements such as obtaining blood samples or repositioning the animal. Records were collected in concert with a suite of other measurements, with no discernible impact on the physiological noise. This allowed for a relatively efficient data collection when compared with behavioral methods that require significant time to train animals and conduct experiments. It is also relatively quick for other AEP audiograms that make take multiple days (sessions). Here we collected seven audiograms over 6 field days (including 1 day with poor weather conditions when no whales were sighted).

Despite the potential challenges of the experiment (cold conditions, electrophysiology close to the water, confined spaces, concurrent measurements potentially introducing noise, and the safety and welfare of the people and animals), the audiograms were of very good quality. They are of equal quality to the field-based collection-release audiometric data of Cook et al. (2004) for bottlenose dolphins (*Tursiops truncates*) and of Nachtigall et al. (2008; see also Mooney et al. 2009) for white-beaked dolphins (*Lagenorhynchus albirostris*) Our success both in the ease and safety of data acquisition and the quality of the data suggests that the methods could easily be applied to other species in similar situations. This is of particular

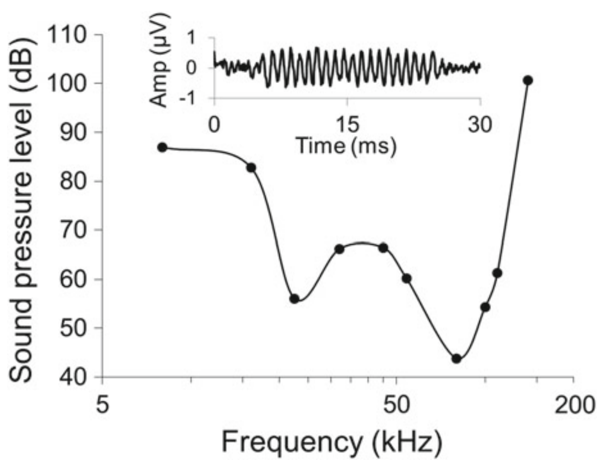

Fig. 88.2 AEP audiogram and waveform (*inset*) of *D. leucas* No. 7. This animal had the overall mean lowest threshold

importance for populations where anthropogenic noise is chronic and has been identified as a potential stressor. Examples are the endangered Cook Inlet *D. leucas* or the threatened St. Lawrence *D. leucas* populations. The prevalence of anthropogenic noise in their habitat and its cumulative effects might be compromising the survival of both *D. leucas* populations (NMFS 2008; DFO 2012). This assertion is based on current knowledge of the level and acuity of anthropogenic noise in these ecosystems (e.g., Gervaise et al. 2012) and our understanding of *D. leucas* hearing and acoustic communication. However, because of the inherent difficulties in evaluating the noise impact on cetaceans, there are no data supporting this hypothesis. Audiograms using the method described here could be collected in the Cook Inlet and in the St. Lawrence Estuary to measure the hearing of *D. leucas* with greater exposure to anthropogenic noise and could then be compared with the baseline audiogram for Bristol Bay *D. leucas*.

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