Analysis of a Blainville's beaked whale movement response to playback of orca calls

Ann N. Allen[1], Ari Daniel Shapiro[1], Andrew Solow[1], Peter L. Tyack[1], Ian Boyd[2], Diane Claridge[3], Christopher Clark[4], David Moretti[5], and Brandon L. Southall[6]

[1] Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA. [2] Sea Mammal Research Unit, School of Biology, University of St. Andrews, Fife, Scotland, KY16, UK. [3] Bahamas Marine Mammal Research Organization, Sandy Point, Abaco, Bahamas. [4] Bioacoustics Research Program, Cornell University, Ithaca, NY 14850, USA. [5] Naval Undersea Warfare Center Division, Code 70T, Bldg. 1351, Newport, RI 02841, USA. [6] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Science and Technology, Ocean Acoustics Program, 1315 East-West Highway, Silver Spring, MD 20910, USA.
Corresponding author: anallen@whoi.edu

Abstract:

Increasing evidence links exposure to Navy mid-frequency active (MFA) sonar with certain mass strandings of odontocetes, particularly deep diving beaked whales. Although the cause of these strandings is unknown, one theory suggests the animals confuse the sonar signals with vocalizations of orcas, a known predator. Here we analyze the movement patterns of a female Blainville's beaked whale (*Mesoplodon densirostris*) in reaction to playbacks of MFA sonar and orca signals. The study was conducted in 2007 at the Atlantic Undersea Test and Evaluation Center (AUTEC) on Andros Island, Bahamas. The study animal was tagged with a suction cup digital acoustic recording tag (DTAG) that recorded acoustic and movement data. Upon completion of one foraging dive, the animal was exposed to a playback of MFA sonar with an initial source level (SL) low enough that the signal was inaudible at the whale's location. The SL was gradually increased over 15 minutes until reaching a maximum received level (RL) at the whale of 147 dB re 1µPa. During the next foraging dive, the whale was exposed to a playback of orca vocalizations, which was also slowly ramped up over 10 minutes to a maximum RL of 126 dB re 1µPa. The movement data were analyzed using a randomization test with a nonparametric density estimate. We found a significant difference in heading distribution after the cessation of the orca playback ($p<0.01$), with the animal maintaining a relatively straight course away from the sound source for an extended period of time. For a beaked whale to be at risk of stranding, it must swim a considerable distance from its deep-water habitat towards shore. The prolonged avoidance response observed here suggests a behavioral reaction that could pose a risk factor for stranding. Further study may reveal what signal types and received levels may induce a prolonged avoidance reaction in beaked whales.

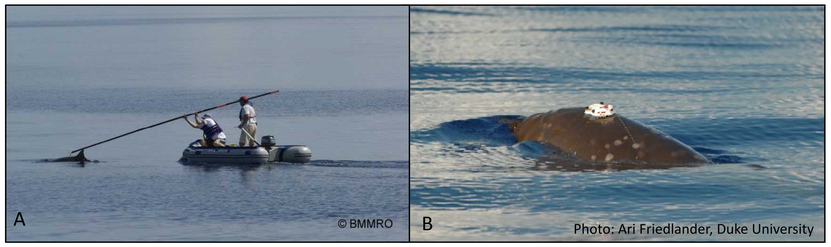
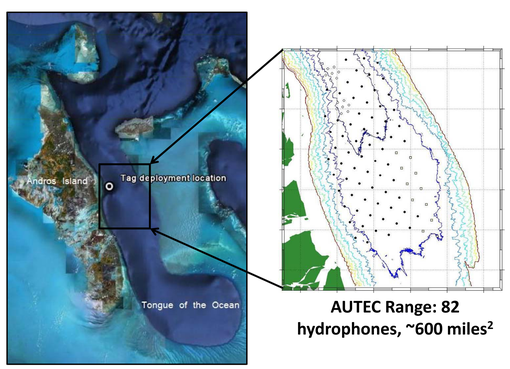


Figure 1: (A) Tagging *M. densirostris* on AUTEC range. (B) Attached DTAG

Introduction:

Multiple atypical mass strandings of deep-diving beaked whales have been documented in association with Navy tests of active sonar (Frantzis 1998) in several different ocean areas. Despite documentation of these associations since the mid 1990s, there has been no direct evidence regarding what causes these strandings. Evidence of the formation of *in vivo* gas bubbles in the tissue of beaked whales stranded after Navy sonar exercises indicates that these animals may suffer from decompression sickness (DCS) following exposure to mid-frequency active (MFA) sonar (Jepson et al. 2003). These gas bubbles may form as a result of a behavioral change in response to naval sonar in which the animals repeatedly dive to a depth shallower than lung collapse, thus facilitating nitrogen supersaturation of tissues and causing DCS (Tyack et al. 2006; Zimmer and Tyack 2007). Although the exact cause of these strandings is still unknown, it has been speculated that the animals may confuse the MFA sonar signals with the predatory vocalizations of orcas and that their avoidance response to this stimulus results in mass strandings of animals. In order to test this theory, this study analyzed the movement data of an individual female Blainville's beaked whale (*Mesoplodon densirostris*) (Fig. 1) during a controlled playback of MFA sonar and orca signals in the 2007 behavioral response study (BRS).

Figure 2: GoogleEarth image of the study area, Andros Island and the Tongue of the Ocean, with the location of the DTAG deployment marked. The hydrophone range is shown in the box on the right, with hydrophones marked as solid or open circles.



AUTEC Range: 82 hydrophones, ~600 miles²

Methods:

The BRS study was conducted in the Tongue of the Ocean (TOTO), a deep canyon near Andros Island, Bahamas, that contains the Atlantic Undersea Test and Evaluation Center (AUTEC) hydrophone range (Fig. 2). A female *M. densirostris* was tagged with a suction cup digital acoustic recording tag (DTAG) that recorded movement as well as acoustic data for over 17 hours. After one pre-exposure dive, the animal was exposed to a playback of MFA sonar with an initial source level (SL) that was inaudible at the whale's location. The SL was gradually increased over 15 minutes until reaching a maximum received level (RL) at the whale of 147 dB re 1µPa. During the animal's next deep foraging dive, a playback of orca sounds was again initiated at low SL and was slowly increased over 10 minutes to a maximum RL of 126 dB re 1µPa. Playback was terminated shortly after an early cessation of foraging clicks was detected. No more playbacks were conducted to this whale and a further 10 hours of acoustic and movement data were recorded after the cessation of the orca playback.

The heading data from the DTAG were analyzed in MATLAB using a nonparametric likelihood ratio (NPLR) test. The NPLR was calculated based on nonparametric kernel density estimates of the probability density functions of the heading data. The data were split into two categories, pre-exposure and post-exposure, based on a hypothetical breakpoint chosen as the time at the end of the orca recording. The change in angle between each heading was calculated and this was then used to calculate the kernel density estimate ($\hat{f}(\theta)$) for both the pre-exposure and post-exposure headings (Fisher 1995):

$$\hat{f}(\theta) = (nh)^{-1} \sum_{i=1}^{n} w\left(\frac{\theta - \theta_i}{h}\right)$$

where:

$$w(\theta) = \begin{cases} 0.9375(1-\theta^2)^2 & -1 \le \theta \le 1 \\ 0 & Otherwise \end{cases}$$

These two values were then used to calculate the likelihood ratio. This process was then repeated for 100 iterations of randomized data order, using the same breakpoint as that in the observed data, and the statistical significance was determined.

Results:

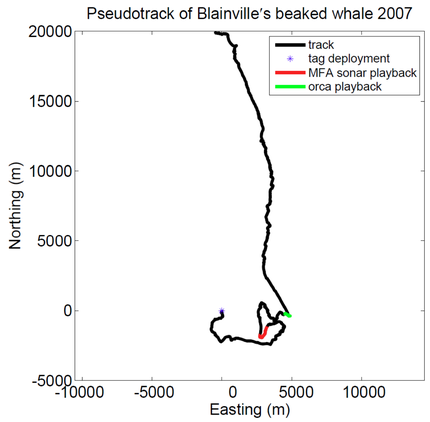


Figure 3: The pseudotrack of the tagged whale. The black track indicates the path of the tagged whale starting at the asterisk. The red section shows the track during the MFA sonar playback and the green shows the track during the orca playback. After the end of the orca playback, the track follows a relatively straight course towards the North for nearly 20km. The psuedotrack is generated from estimations of the speed of the whale and does not take into account ocean currents. The details are not accurate and will be improved with georeferencing.

- Upon cessation of orca playback, the tagged whale changed course and began swimming on a relatively straight course away from the sound source and towards the northern end of the TOTO canyon (Fig. 3)
- During the 10 hours of post-exposure recording, the whale executed two more deep foraging dives, while still maintaining a northerly course
- Change in heading data show less variation after cessation of orca playback (Fig. 4) indicating a relatively straight course
- The likelihood ratio (LR) for the observed data is large and well outside the range of LRs calculated for the randomized data, indicating that there is a significant difference in heading distribution after the cessation of the orca playback ($p<0.01$) (Fig. 5)

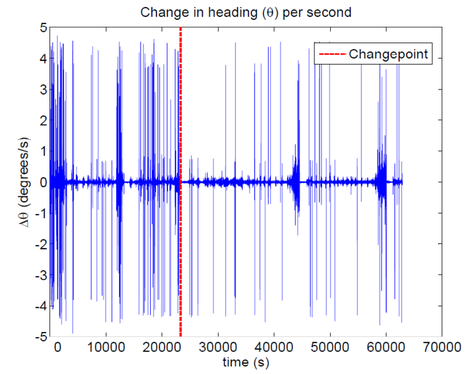


Figure 4: The change in heading for the duration of the dive record. After the indicated changepoint, the variation in heading is reduced as the whale travels on a relatively straight course.

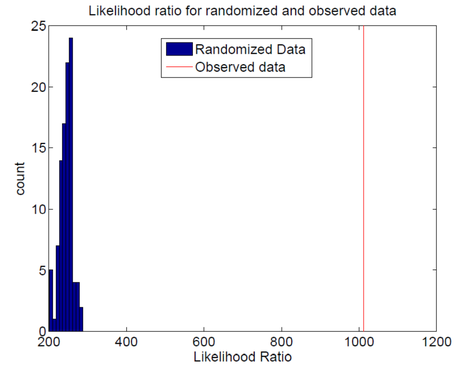


Figure 5: The calculated likelihood ratio for the observed data as well as a histogram of the likelihood ratios calculated for 100 randomization tests. The observed data is well outside the distribution of randomized values. This indicates a significant difference between the data before and after the breakpoint.

Conclusions:

- This study shows a clear behavioral avoidance response of an adult female beaked whale to playback of MFA sonar and orca sounds
- A prolonged avoidance response, as demonstrated here, could pose a risk factor for stranding as the whale swims quickly away from deep-water foraging grounds
- Further analysis of changes in diving and movement patterns may reveal additional risk factors for stranding
- Continued study of the movement data will focus on pinpointing the exact timing of the change in swimming behavior

Acknowledgements:

We thank the entire BRS team, who are too numerous to mention here, for their hard work and patience which made this study possible, even in light of the abundant challenges associated with working with beaked whales. Funding was provided by the US Navy Chief of Naval Operations' Submarine Warfare Division (Undersea Surveillance), the US Navy Environmental Readiness Division, the US Office of Naval Research, the Oil and Gas Producers Joint Industry Program on Sound and Marine Life, the US Department of Defense Strategic Environmental Research and Development Program (SERDP), and the US National Oceanic and Atmospheric Administration (National Marine Fisheries Service, Office of Science and Technology). Research was conducted under US NMFS permits 1121-1900 (J. Boreman and B. Southall) and 981-1578 (P. Tyack), Bahamas permit #01/09 (Bahamas Marine Mammal Research Organisation) and Bahamas permit #02/07 and #02/08 (I. Boyd). The experimental research was approved by the WHOI and BMMRO Institutional Animal Care and Use Committees.

References:

•Fisher, N.I. 1995. Statistical analysis of circular data. Cambridge University Press, New York.
•Frantzis, A. 1998. Does acoustic testing strand whales? Nature 392:29.
•Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herraez, A.M. Pocknell, F. Rodgrigues, F.E. Howiell, A. Espinosa, R.J. Reid, J.R. Jabert, V. Martin, A.A. Cunningham and A. Fernandez. 2003. Gas-bubble lesions in stranded cetaceans. Nature 425:575.
•Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese and P.T. Madsen. 2006. Extreme diving of beaked whales. The Journal of Experimental Biology 209:4238-4253.
•Zimmer, W.M.X. and P.L. Tyack. 2007. Repetitive shallow dives pose decompression risk in deep-diving beaked whales. Marine Mammal Science 23(4):888-925.