The Behavioral Ecology of BRS

Andy Read
Nicholas School of the Environment
Duke University

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NICHOLAS SCHOOL OF THE ENVIRONMENT

A Typical Controlled Exposure Experiment

Selection and tagging of focal animal

Exposure to acoustic stimuli

Monitoring of behavioral response

I will use tactical sonars as the stimulus type and restrict my review to published descriptions of CEEs - I won’t discuss observational or captive studies

Behavioral Response Studies Are Particularly Difficult

Logistical challenges

Field trials are expensive

Sample sizes are typically very small

Experiments are typically of short duration

Responses can be very difficult to interpret

The Risk-Disturbance Hypothesis

If cetaceans perceive (or respond to) the acoustic stimulus as a potential threat, similar to that of the detection of a predator, then the response should reflect the species-specific anti-predator strategy.

"…the principle that nonlethal disturbance stimuli caused by humans are analogous to predation risk."

Frid & Dill (2002) Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* 6(1): 11.

Generalized Response to Perceived Threats

Prediction:

The response to a MFAS signal should reflect a species-specific anti-predator strategy and that this response should be mediated by factors (trade-offs) specific to the focal individual and it's social group

More about playbacks of predator calls from Doug later this morning

and

Charlotte Curé *et al*. Using behavioural responses of sperm whales to predator sound playbacks as a reference of disturbance to assess impact of naval sonar. Monday at 13:45

Interpreting Response Within an Anti-Predator Context

Species-specific variation

- Flight, fight or social defense

As modified by behavioral context

- Behavioral state at time of exposure
- Composition of social group
- Perception of experimental stimulus
- Habituation - history of prior exposure

How Do We Deal With Context?

1. For species which are relatively easy to study, conduct CEEs under a variety of conditions (*e.g.* behavioral state) and consider these states as covariates.

2. For other species, restrict CEEs to certain conditions.

3. Collect baseline data to better understand some of the drivers of variation in response (e.g. Quick *et al*. Monday 15:00).

4. Map prey fields of those species whose response will likely be mediated by the presence of a profitable prey patch.

5. To gain insight into the effects of prior exposure, compare response of focal species on and away from active training ranges.

Predicted Species-Specific Variation in Response

Mysticetes

Balaenoptera	Flight
Balaena	Physical Defense
Eschrichtius	Physical Defense
Eubalaena	Physical Defense
Megaptera	Physical Defense

Odontocetes

Globicephala	Social Defense
Physeter	Social Defense
Mesoplodon	Flight
Ziphius	Flight
Berardius (?)	Social Defense
Hyperoodon (?)	Social Defense

Mammal Rev. 2008, Volume 38, No. 1, 50–86. *Printed in Singapore.*

Fight or flight: antipredator strategies of baleen whales

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ABSTRACT

1. The significance of killer whale *Orcinus orca* predation on baleen whales (Mysticeti) has been a topic of considerable discussion and debate in recent years. Discourse has been constrained by poor understanding of predator-prey dynamics, including the relative vulnerability of different mysticete species and age classes to killer whales and how these prey animals avoid predation. Here we provide an overview and analysis of predatory interactions between killer whales and mysticetes, with an emphasis on patterns of antipredator responses.

2. Responses of baleen whales to predatory advances and attacks by killer whales appear to fall into two distinct categories, which we term the *fight* and *flight* strategies. The *fight* strategy consists of active physical defence, including self-defence by single individuals, defence of calves by their mothers and coordinated defence by groups of whales. It is documented for five mysticetes: southern right whale *Eubalaena australis*, North Atlantic right whale *Eubalaena glacialis*, bowhead whale *Balaena mysticetus*, humpback whale *Megaptera novaeangliae* and grey whale *Eschrichtius robustus*. The *flight* strategy consists of rapid (20–40 km/h) directional swimming away from killer whales and, if overtaken and attacked, individuals do little to defend themselves. This strategy is documented for six species in the genus *Balaenoptera*.

3. Many aspects of the life history, behaviour and morphology of mysticetes are consistent with their antipredator strategy, and we propose that evolution of these traits has been shaped by selection for reduced predation. *Fight* species tend to have robust body shapes and are slow but relatively manoeuvrable swimmers. They often calve or migrate in coastal areas where proximity to shallow water provides refuge and an advantage in defence. Most *fight* species have either callosities (rough and hardened patches of skin) or encrustations of barnacles on their bodies, which may serve (either primarily or secondarily) as weapons or armour for defence. *Flight* species have streamlined body shapes for high-speed swimming and they can sustain speeds necessary to outrun pursuing killer whales (>15–20 km/h). These species tend to favour pelagic habitats and calving grounds where prolonged escape sprints from killer whales are possible.

4. The rarity of observed successful attacks by killer whales on baleen whales, especially adults, may be an indication of the effectiveness of these antipredator strategies. Baleen whales likely offer low profitability to killer whales, relative to some other marine mammal prey. High-speed pursuit of *flight* species has a high energetic cost and a low probability of success while attacks on *fight* species can involve prolonged handling times and a risk of serious injury.

Keywords: cetacean, defence, killer whale, *Orcinus orca*, predation, predator avoidance

Blainville's Beaked Whales

Stimulus: Simulated MFAS

Predicted Response: Flight

n = 1

OPEN ACCESS Freely available online

PLoS one

Beaked Whales Respond to Simulated and Actual Navy Sonar

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Abstract

Beaked whales have mass stranded during some naval sonar exercises, but the cause is unknown. They are difficult to sight but can reliably be detected by listening for echolocation clicks produced during deep foraging dives. Listening for these clicks, we documented Blainville's beaked whales, *Mesoplodon densirostris*, in a naval underwater range where sonars are in regular use near Andros Island, Bahamas. An array of bottom-mounted hydrophones can detect beaked whales when they click anywhere within the range. We used two complementary methods to investigate behavioral responses of beaked whales to sonar: an opportunistic approach that monitored whale responses to multi-day naval exercises involving tactical mid-frequency sonars, and an experimental approach using playbacks of simulated sonar and control sounds to whales tagged with a device that records sound, movement, and orientation. Here we show that in both exposure conditions beaked whales stopped echolocating during deep foraging dives and moved away. During actual sonar exercises, beaked whales were primarily detected near the periphery of the range, on average 16 km away from the sonar transmissions. Once the exercise stopped, beaked whales gradually filled in the center of the range over 2–3 days. A satellite tagged whale moved outside the range during an exercise, returning over 2–3 days post-exercise. The experimental approach used tags to measure acoustic exposure and behavioral reactions of beaked whales to one controlled exposure each of simulated military sonar, killer whale calls, and band-limited noise. The beaked whales reacted to these three sound playbacks at sound pressure levels below 142 dB re 1 µPa by stopping echolocation followed by unusually long and slow ascents from their foraging dives. The combined results indicate similar disruption of foraging behavior and avoidance by beaked whales in the two different contexts, at exposures well below those used by regulators to define disturbance.

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Competing Interests: While the sponsors of this study come from an international mix of sound producers and a United States regulatory agency, the majority of funding for the research reported here comes from different divisions of the U.S. Navy, and all of the authors have had at least some of the research reported here partially funded by different divisions of the U.S. Navy. The following authors are employed by the U.S. Navy: David Moretti, Angela D'Amico, Nancy DiMarzio, Susan Jarvis, Elena McCarthy, Ronald Morrissey, and Jessica Ward. Their primary involvement was in designing, installing, and helping to operate the passive acoustic marine mammal monitoring system at the AUTEC range; providing the sound sources used in the experiments; and with analyzing and writing up the data. During the time period covered by this research the following authors were employed by the National Marine Fisheries Service of the U.S. National Oceanic and Atmospheric Administration, which acts as the federal regulatory agency for protection of marine mammals: Brandon Southall and John Durban. The following authors have been asked by the U.S. Department of Justice to act as expert witnesses in cases involving the effects of naval sonar on marine mammals: Christopher Clark, Brandon Southall, and Peter Tyack. Peter Tyack is a member of Natural Resources Defense Council, which is an advocacy organization that has sued the Navy concerning effects of sonar on marine mammals. None of the analysis nor write up of the paper involved or was influenced by the sponsors of the research.

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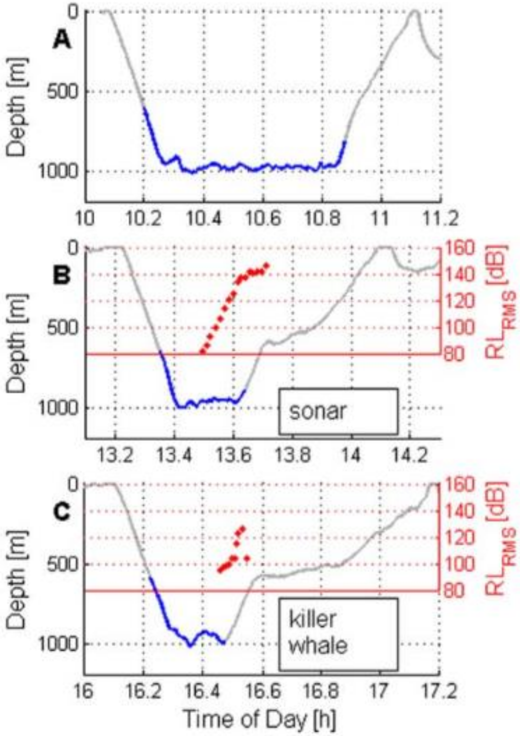
Introduction

Over the past 20 years, there has been increasing concern that noise from human activities may affect wildlife. Recent work has identified impacts of anthropogenic sound on terrestrial birds [1] and anurans [2]. Sound propagates underwater with much less loss than in air, so sounds produced underwater may impact animals over greater ranges than sounds produced in air. The first alarms

Blainville's Beaked Whales



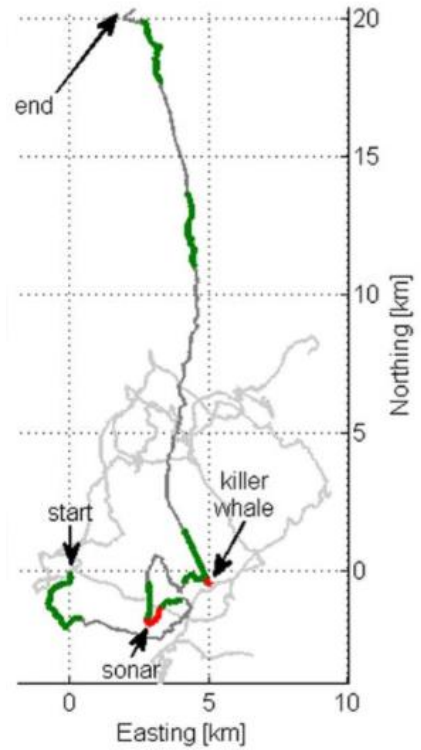
Pre-Exposure

Simulated MFAS

Killer Whale

When exposed to simulated MFAS, this whale stopped echolocating, ascended slowly and moved away from the source

Blainville's Beaked Whales



The whale reacted to the killer whale calls (at lower RLs) by stopping echolocation, ascending slowly and then moving away from the source for 10 hours

Cuvier’s Beaked Whales

Stimulus: Simulated MFAS

Predicted Response: Flight

$n = 2$

biology letters

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Research

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Cite this article: DeRuiter SL, Southall BL, Calambokidis J, Zimmer WMX, Sadykova D, Falcone EA, Friedlaender AS, Joseph JE, Moretti D, Schorr GS, Thomas L, Tyack PL. 2013 First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar. Biol Lett 9: 20130223. http://dx.doi.org/10.1098/rsbl.2013.0223

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Conservation biology

First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar

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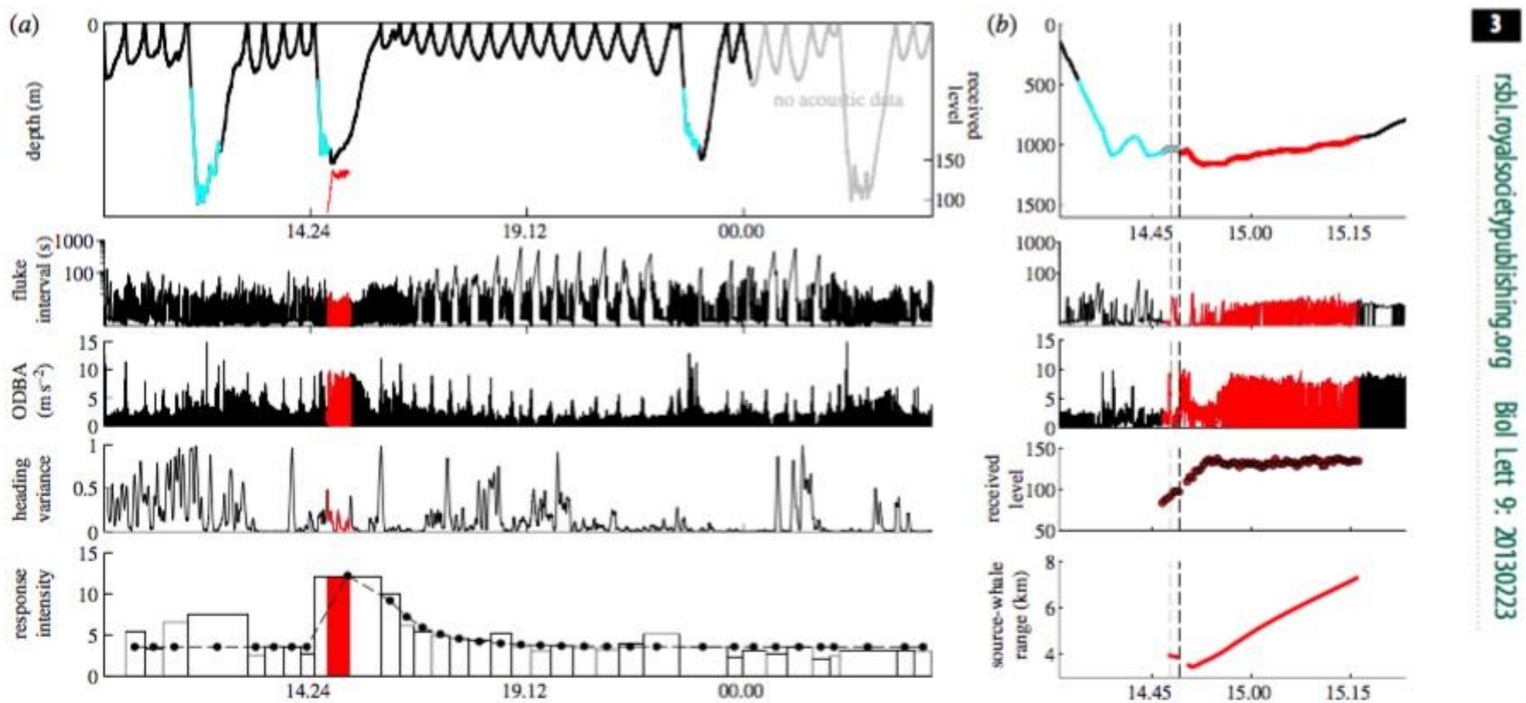
Most marine mammal strandings coincident with naval sonar exercises have involved Cuvier's beaked whales (*Ziphius cavirostris*). We recorded animal movement and acoustic data on two tagged *Ziphius* and obtained the first direct measurements of behavioural responses of this species to mid-frequency active (MFA) sonar signals. Each recording included a 30-min playback (one 1.6-s simulated MFA sonar signal repeated every 25 s); one whale was also incidentally exposed to MFA sonar from distant naval exercises. Whales responded strongly to playbacks at low received levels (RLs; 89–127 dB re 1 μPa): after ceasing normal fluking and echolocation, they swam rapidly, silently away, extending both dive duration and subsequent non-foraging interval. Distant sonar exercises (78–106 dB re 1 μPa) did not elicit such responses, suggesting that context may moderate reactions. The observed responses to playback occurred at RLs well below current regulatory thresholds; equivalent responses to operational sonars could elevate stranding risk and reduce foraging efficiency.

1. Introduction

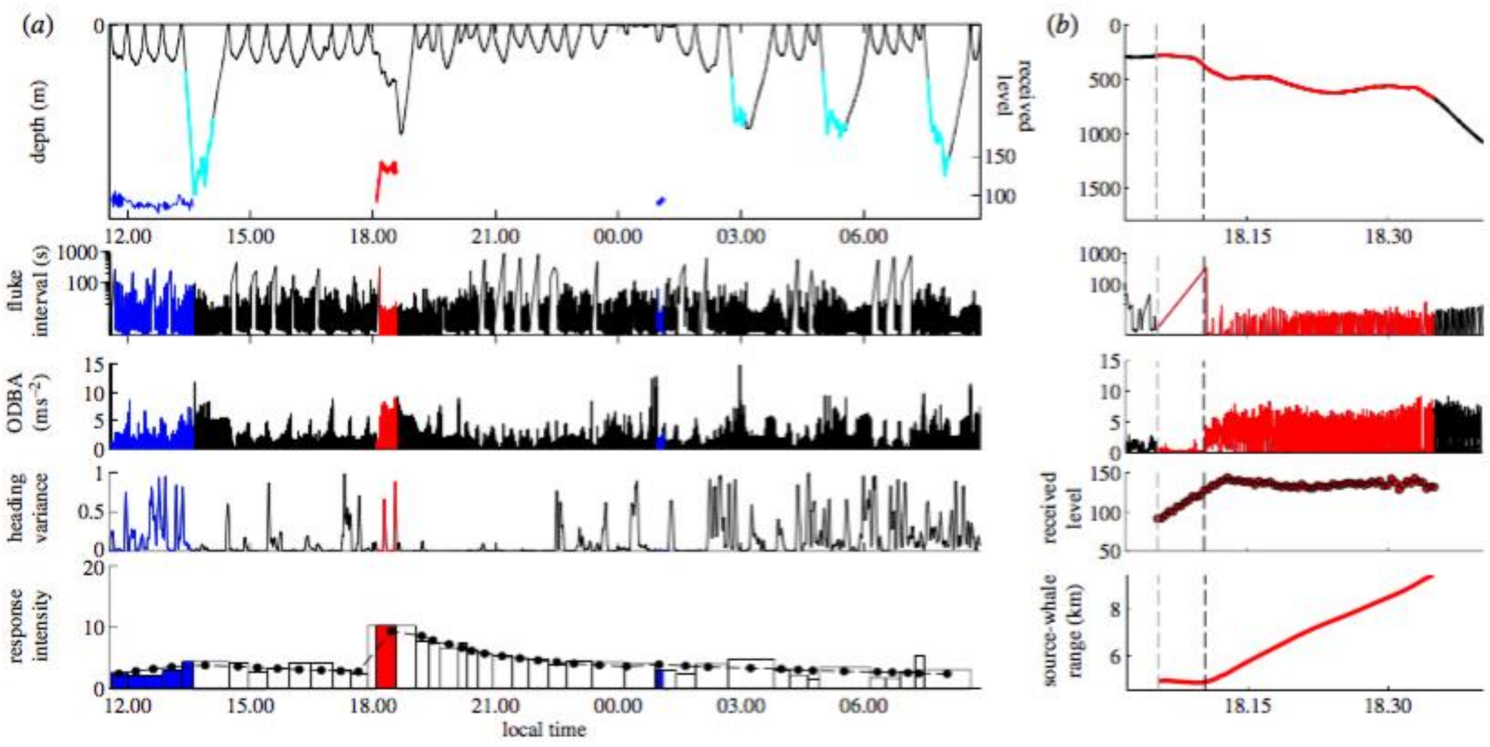
Unusual mass strandings of cetaceans, especially beaked whales, have been associated with the operation of military mid-frequency active (MFA) sonars; these sometimes fatal events have raised serious concern about impacts of sonar and other anthropogenic sounds on whales [1–3]. Behavioural responses to MFA sonar are thought to play an important role in the series of events that leads to such strandings [1]. An on-going series of controlled exposure experiments (CEEs) and opportunistic studies have begun to provide data on behavioural responses to MFA sonar by species including Blainville's beaked whales (*Mesoplodon densirostris*; [4]). Cuvier's beaked whales (*Ziphius cavirostris* Cuvier) make up the majority of fatalities in MFA-associated strandings [5], and *Ziphius* abundance along the US west coast is apparently declining [6], but until

Cuvier's Beaked Whales



When exposed to simulated MFAS, this whale stopped echolocating and exhibited a strong avoidance response that included energetic swimming away from the source

Cuvier's Beaked Whales



A second whale responded differentially to the distant, incidental exposure of real MFAS and nearby CEE of simulated MFAS, even though Received Levels of the two exposures were comparable

Northern Bottlenose Whales

Stimulus: MFAS

Predicted Response: Social Defense (?)

n = 1

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Research

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First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise

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Although northern bottlenose whales were the most heavily hunted beaked whale, we have little information about this species in its remote habitat of the North Atlantic Ocean. Underwater anthropogenic noise and disruption of their natural habitat may be major threats, given the sensitivity of other beaked whales to such noise disturbance. We attached dataloggers to 13 northern bottlenose whales and compared their natural sounds and movements to those of one individual exposed to

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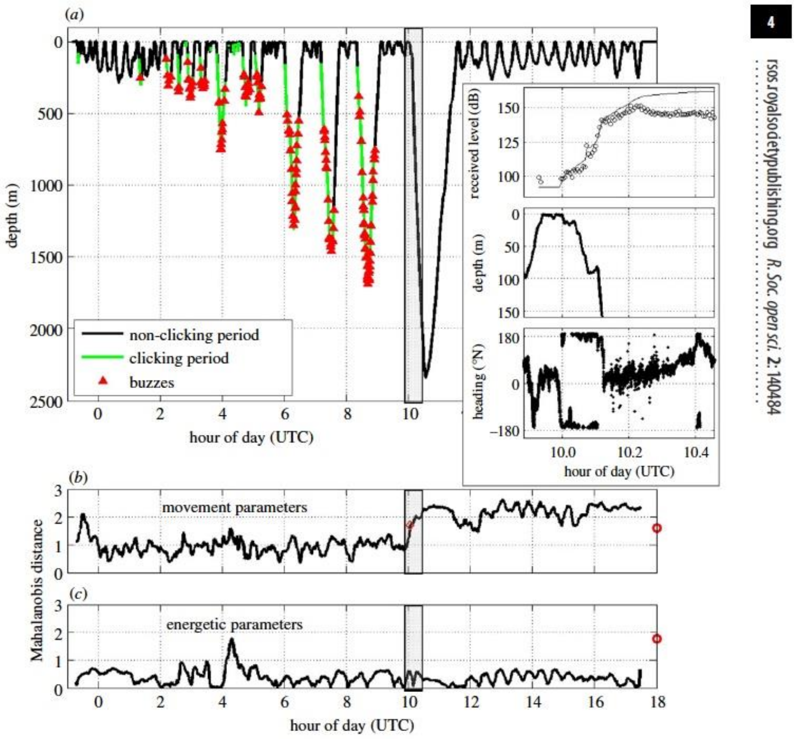
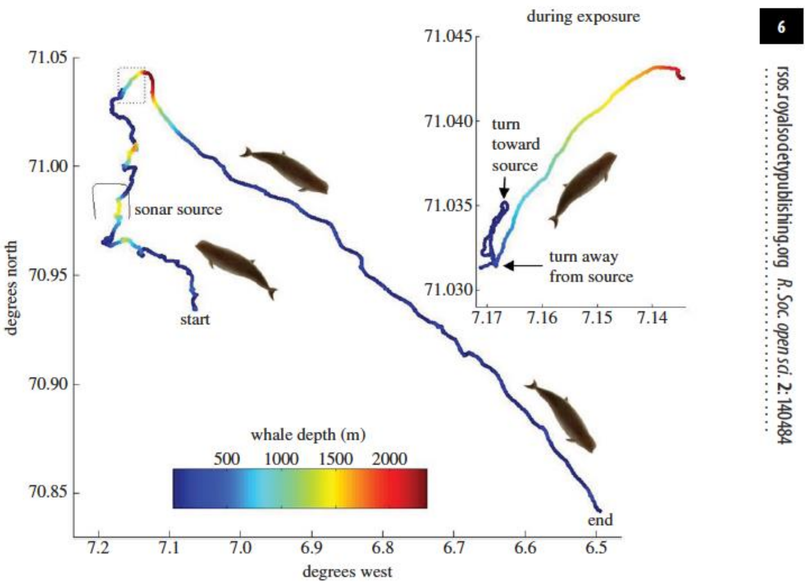
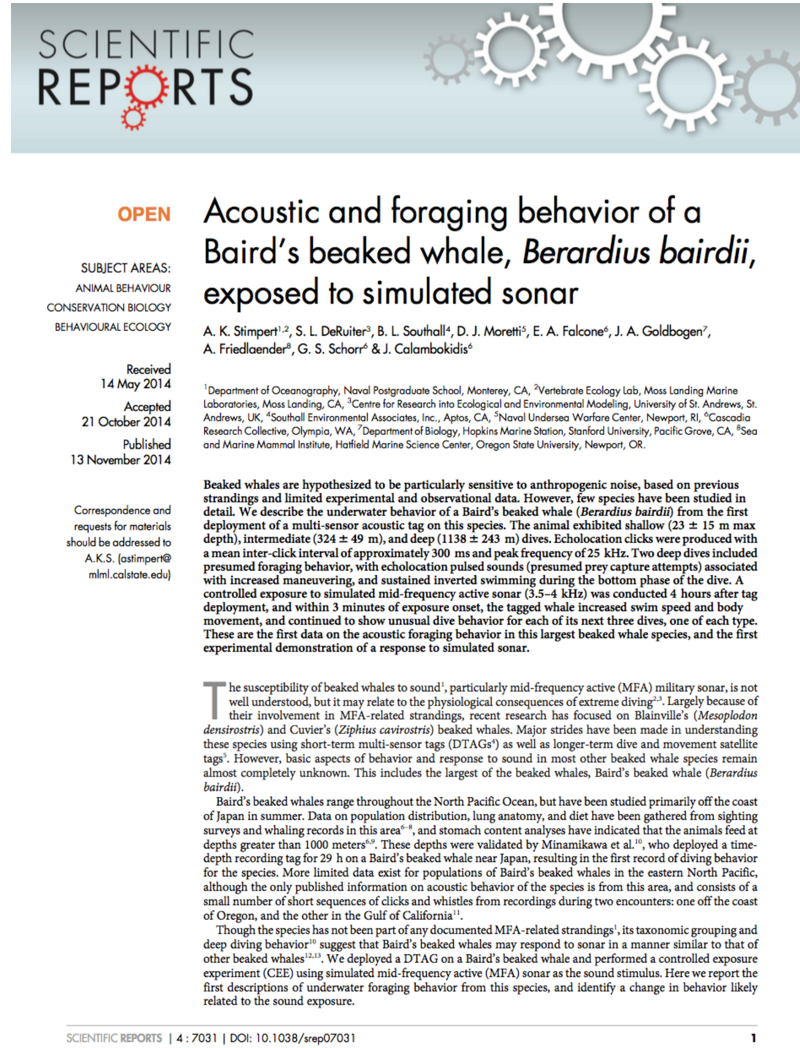
Northern Bottlenose Whales





The whale initially turned towards the source, then dove deeply without echolocating, and moved away from the source in a series of shallow dives for seven hours

Baird’s Beaked Whales



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Acoustic and foraging behavior of a Baird’s beaked whale, *Berardius bairdii*, exposed to simulated sonar

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Beaked whales are hypothesized to be particularly sensitive to anthropogenic noise, based on previous strandings and limited experimental and observational data. However, few species have been studied in detail. We describe the underwater behavior of a Baird’s beaked whale (*Berardius bairdii*) from the first deployment of a multi-sensor acoustic tag on this species. The animal exhibited shallow (23 ± 15 m max depth), intermediate (324 ± 49 m), and deep (1138 ± 243 m) dives. Echolocation clicks were produced with a mean inter-click interval of approximately 300 ms and peak frequency of 25 kHz. Two deep dives included presumed foraging behavior, with echolocation pulsed sounds (presumed prey capture attempts) associated with increased maneuvering, and sustained inverted swimming during the bottom phase of the dive. A controlled exposure to simulated mid-frequency active sonar (3.5–4 kHz) was conducted 4 hours after tag deployment, and within 3 minutes of exposure onset, the tagged whale increased swim speed and body movement, and continued to show unusual dive behavior for each of its next three dives, one of each type. These are the first data on the acoustic foraging behavior in this largest beaked whale species, and the first experimental demonstration of a response to simulated sonar.

The susceptibility of beaked whales to sound[1], particularly mid-frequency active (MFA) military sonar, is not well understood, but it may relate to the physiological consequences of extreme diving[2,3]. Largely because of their involvement in MFA-related strandings, recent research has focused on Blainville’s (*Mesoplodon densirostris*) and Cuvier’s (*Ziphius cavirostris*) beaked whales. Major strides have been made in understanding these species using short-term multi-sensor tags (DTAGs[4]) as well as longer-term dive and movement satellite tags[5]. However, basic aspects of behavior and response to sound in most other beaked whale species remain almost completely unknown. This includes the largest of the beaked whales, Baird’s beaked whale (*Berardius bairdii*).

Baird’s beaked whales range throughout the North Pacific Ocean, but have been studied primarily off the coast of Japan in summer. Data on population distribution, lung anatomy, and diet have been gathered from sighting surveys and whaling records in this area[6–8], and stomach content analyses have indicated that the animals feed at depths greater than 1000 meters[6,9]. These depths were validated by Minamikawa et al.[10], who deployed a time-depth recording tag for 29 h on a Baird’s beaked whale near Japan, resulting in the first record of diving behavior for the species. More limited data exist for populations of Baird’s beaked whales in the eastern North Pacific, although the only published information on acoustic behavior of the species is from this area, and consists of a small number of short sequences of clicks and whistles from recordings during two encounters: one off the coast of Oregon, and the other in the Gulf of California[11].

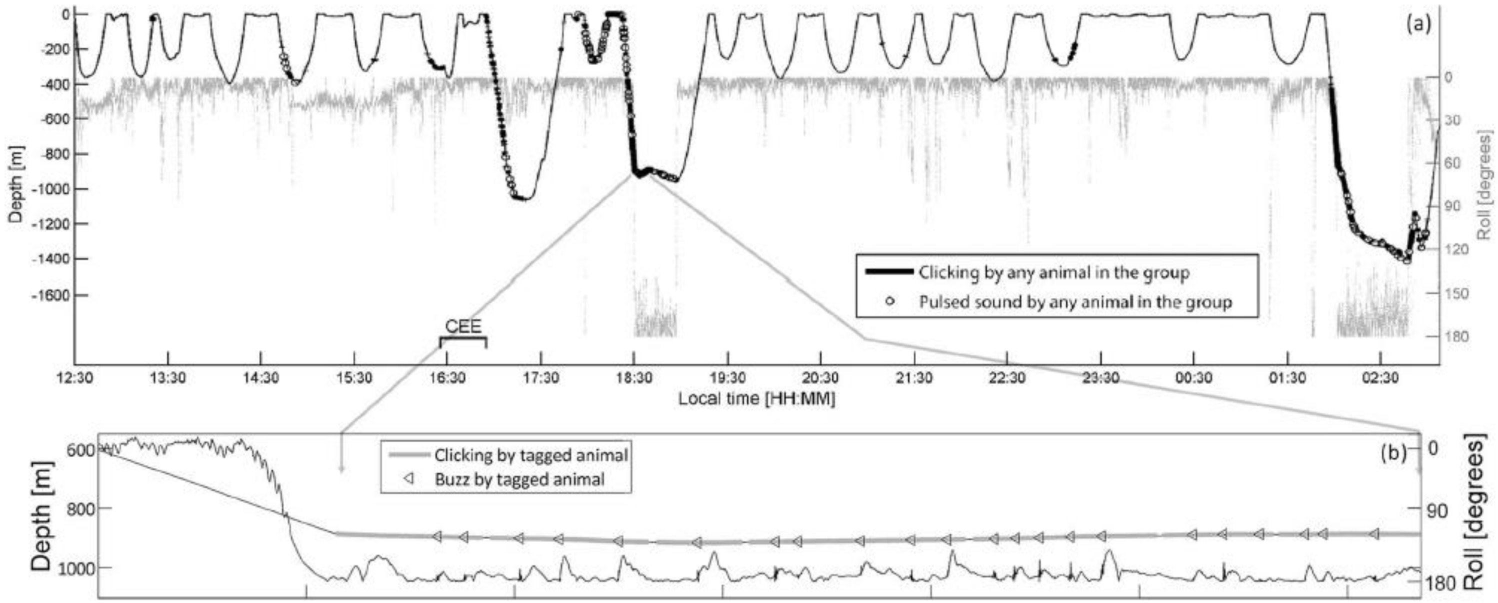
Though the species has not been part of any documented MFA-related strandings[1], its taxonomic grouping and deep diving behavior[10] suggest that Baird’s beaked whales may respond to sonar in a manner similar to that of other beaked whales[12,13]. We deployed a DTAG on a Baird’s beaked whale and performed a controlled exposure experiment (CEE) using simulated mid-frequency active (MFA) sonar as the sound stimulus. Here we report the first descriptions of underwater foraging behavior from this species, and identify a change in behavior likely related to the sound exposure.

Stimulus: Simulated MFAS

Predicted Response: Social Defense (?)

n = 1

Baird's Beaked Whales



The whale exhibited a mild behavioral response for the duration of the exposure, without moving away from the source, and the group soon resumed foraging

Blue Whales

Stimulus: Simulated MFAS

Predicted Response: Flight (?)

n = 17

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Blue whales respond to simulated mid-frequency military sonar

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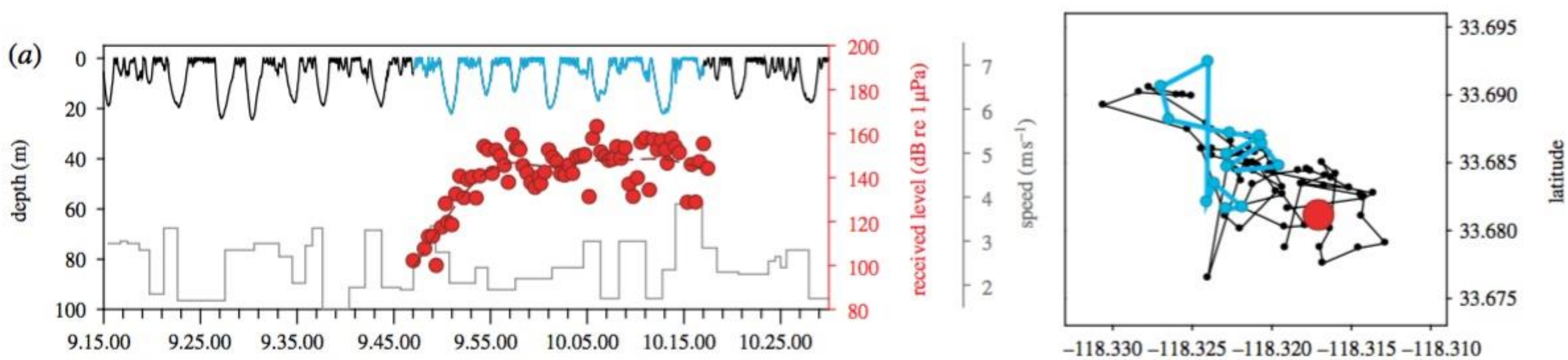
Mid-frequency military (1–10 kHz) sonars have been associated with lethal mass strandings of deep-diving toothed whales, but the effects on endangered baleen whale species are virtually unknown. Here, we used controlled exposure experiments with simulated military sonar and other mid-frequency sounds to measure behavioural responses of tagged blue whales (*Balaenoptera musculus*) in feeding areas within the Southern California Bight. Despite using source levels orders of magnitude below some operational military systems, our results demonstrate that mid-frequency sound can significantly affect blue whale behaviour, especially during deep feeding modes. When a response occurred, behavioural changes varied widely from cessation of deep feeding to increased swimming speed and directed travel away from the sound source. The variability of these behavioural responses was largely influenced by a complex interaction of behavioural state, the type of mid-frequency sound and received sound level. Sonar-induced disruption of feeding and displacement from high-quality prey patches could have significant and previously undocumented impacts on baleen whale foraging ecology, individual fitness and population health.

1. Introduction

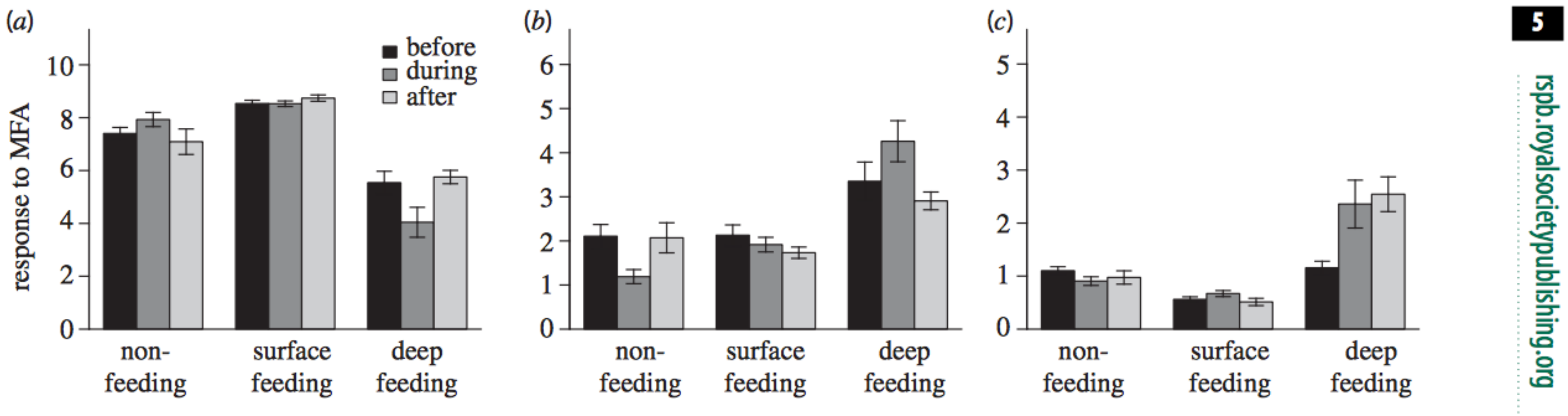
Mounting evidence suggests that anthropogenic noise can harm marine life [1–6]. The first concerns were that low-frequency anthropogenic noise could mask calling behaviour in baleen whales (Mysticeti), thereby reducing their communication range [7,8], and that intense levels of noise could also damage hearing [1]. These effects continue to be a high priority for the management and conservation of cetaceans owing to worldwide shipping traffic and resource extraction in environmentally sensitive and critical habitats such as the Arctic [9]. Recent mass stranding events and mortality of cetaceans have been linked to mid-frequency active (MFA) military sonar (i.e. range: 1–10 kHz) [3,10–13]. The strong impact of mid-frequency naval sonar is puzzling because the frequency of the sounds and best hearing of many toothed whales (Odontoceti) are much higher than mid-frequency sonar [14], and the communication band of mysticetes is generally much lower. Most environmental reviews have discounted the effects of noise outside the predominant communication band for many species, especially

Blue Whales



Blue whales feeding at the surface exhibited little, if any, response when exposed to simulated MFAS signals

Blue Whales



Diving

Body Orientation

Displacement

Blue whales engaged in other behavior exhibited brief avoidance responses when exposed to simulated MFAS signals

Conclusions

1. Most of the species examined to date have responded to MFAS signals in a manner consistent with our predicted responses to the calls of predators.

2. Our understanding of the anti-predator response in many species is very rudimentary and certainly worthy of further study.

3. The behavioral and ecological context in which a signal is received is important and complicates our interpretation of the responses observed.

4. It would be useful to examine other species that are relatively easy to study, to address the effects of behavioral state and other sources of behavioral context.

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