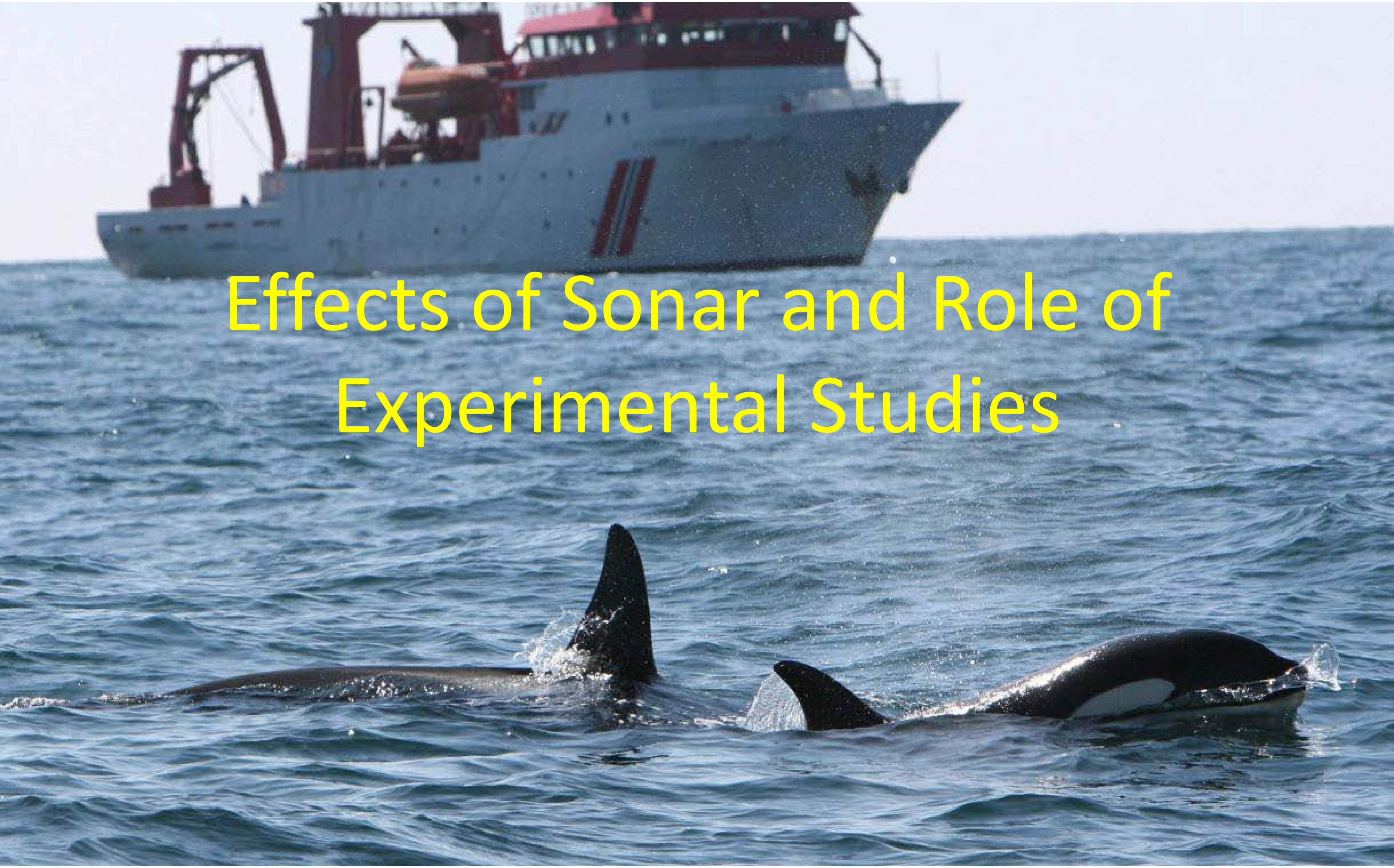
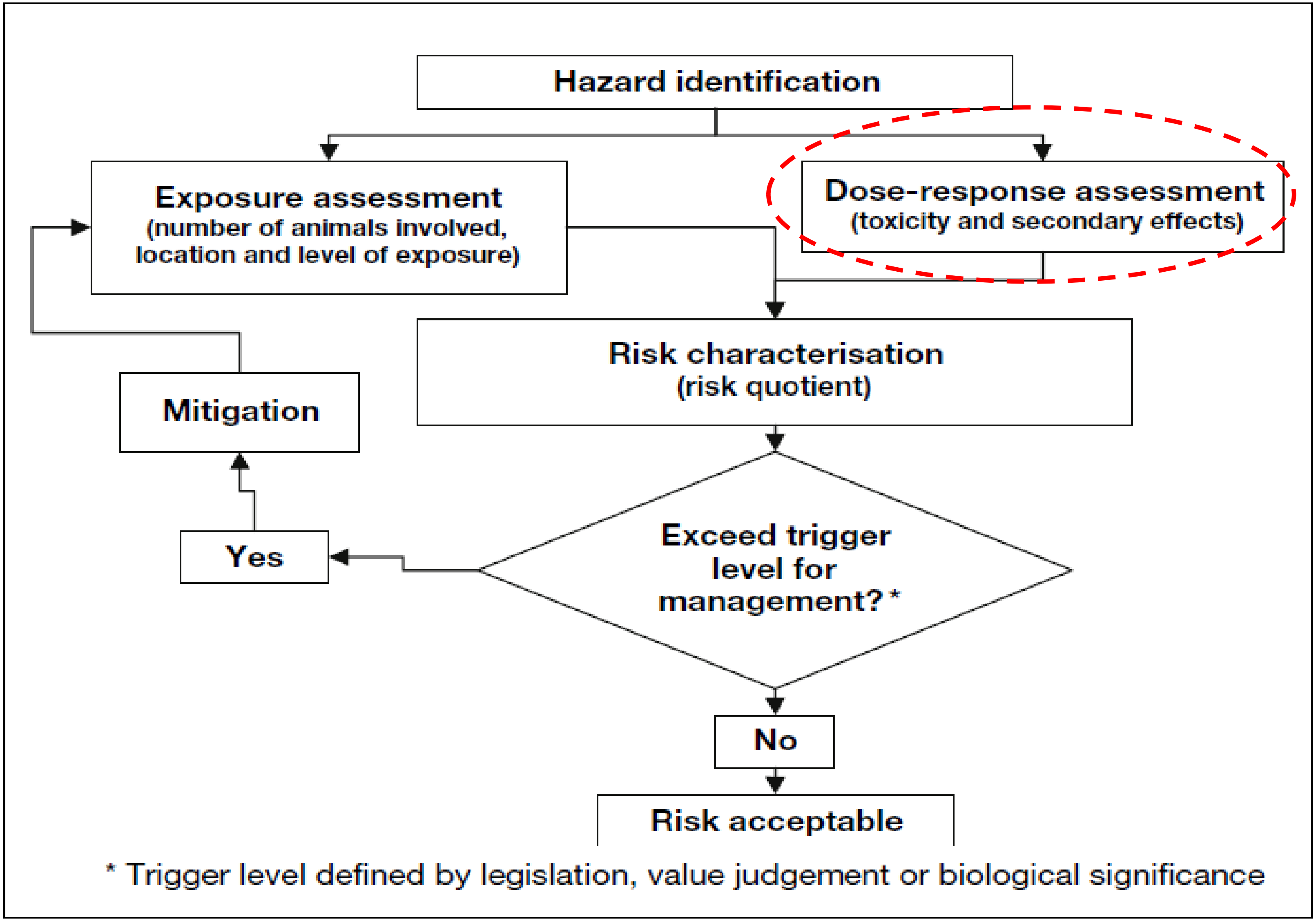
Sea Mammals & Sonar Symposium 27 October 2015



Effects of Sonar and Role of Experimental Studies

Peter L. Tyack Sea Mammal Research Unit University of St Andrews

Risk Assessment Model



European Science Foundation (2008) The effects of anthropogenic sound on marine mammals. http://www.esf.org/fileadmin/Public_documents/Publications/MBpp13.pdf

Drivers for Studying Effects of Sonar

Need to know:

- How exactly do whales respond to sonar?
- What factors affect risk of adverse response?
  - Linked to exposure
    - Acoustic: Received Level (Sound Pressure Level, Sound Exposure Level, Rise time, Duration, Duty Cycle)
    - Other: (Range to ship, movement of ship, bathymetry, propagation conditions)
  - Intrinsic to animal – species, behavioral context, condition
- Only experiments can prove causation. Powerful observational methods can define responses
- Once responses have been defined, this can be used to design monitoring to detect them

Experiments in Captivity or Wild?

- Captivity
  - Relatively cheap
  - Easier to control context and know health of subject
  - Easier to study effects of repeated exposure
- Wild
  - Ecologically valid setting
  - Response measured takes the current mixture of environmental stressors into account
  - Better for interpreting biological significance in terms of effects on growth, reproduction, and survival

Basic Design of Free-ranging CEEs

- Select site and target species
- Requires some behavioral ecology background, ideally before CEEs are planned
- Select subject (ideally at random from population)
  - Collect pre-exposure baseline
  - 1 or more exposures to control or various stimuli (ideally randomize order). Beneficial to test same individual with several stimuli to control for individual differences
  - Monitor return to baseline

Critical features of free-range CEEs

- Use specific protocol to test for specific kinds of reaction related to adverse impact
- Start at low exposure levels, increase until response observed or max level reached. Dose escalation can be achieved by increasing source level and / or approaching subject
- Quantify exposure associated with response
- Avoid exposures high enough for risk of injury

Two modes for studying response

- Decide ahead of time what responses are most relevant to the policy context, e.g.
  - Avoidance
  - Foraging energetics
- Aim to test for ANY relevant response
  - Basic approach is to use multi-sensor tags to sample behavior in enough detail to capture any relevant response
  - Use expert evaluation and/or multivariate statistics to define response

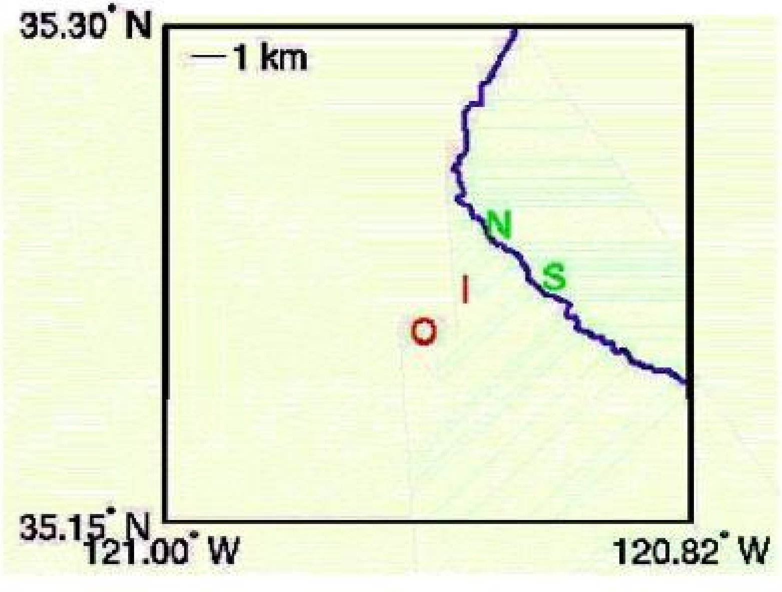
DTAG

Studies where response was decided ahead of time

- Do Gray Whales Avoid Low Frequency Sonar?
- Study on effects of seismic survey on sperm whales decided to evaluate foraging energetics
- 3S project was initially stimulated by concerns of whale-watchers and NGOs that sonar exercises in coastal Norwegian waters had caused killer whales to leave the area. This led 3S to need to address avoidance responses.

Initial Behavioral Response Studies on Gray whales migrating past the Central California Coast

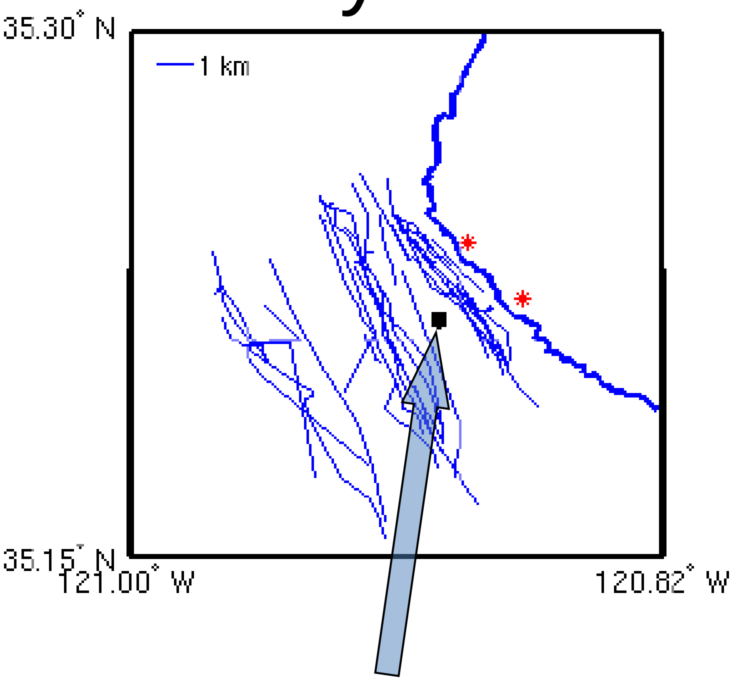
- Dozens of whale groups migrating past site each day
- Land-based Observers track whales
- Paired Playback/Control Design
- Sound source moored offshore



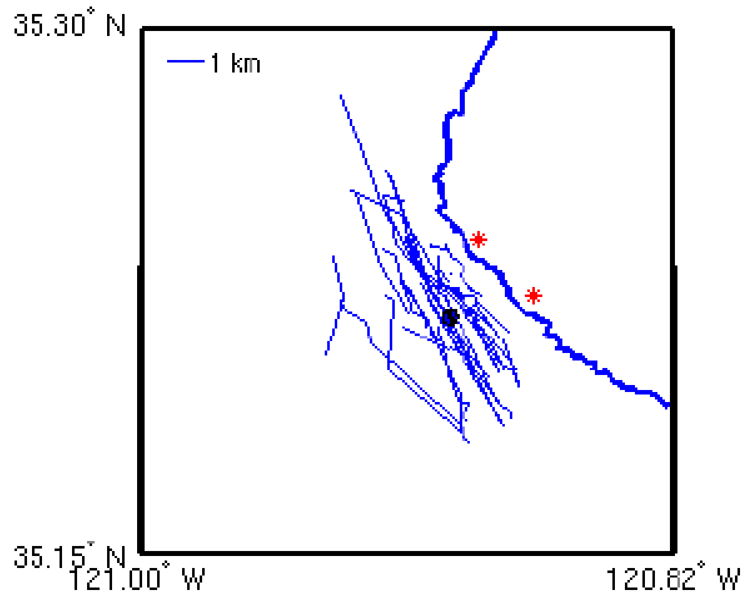
Responses of migrating gray whales to SURTASS Low Frequency Sonar

160-330 Hz, 42 s every 6 min
Source Level = 185 dB

Playback

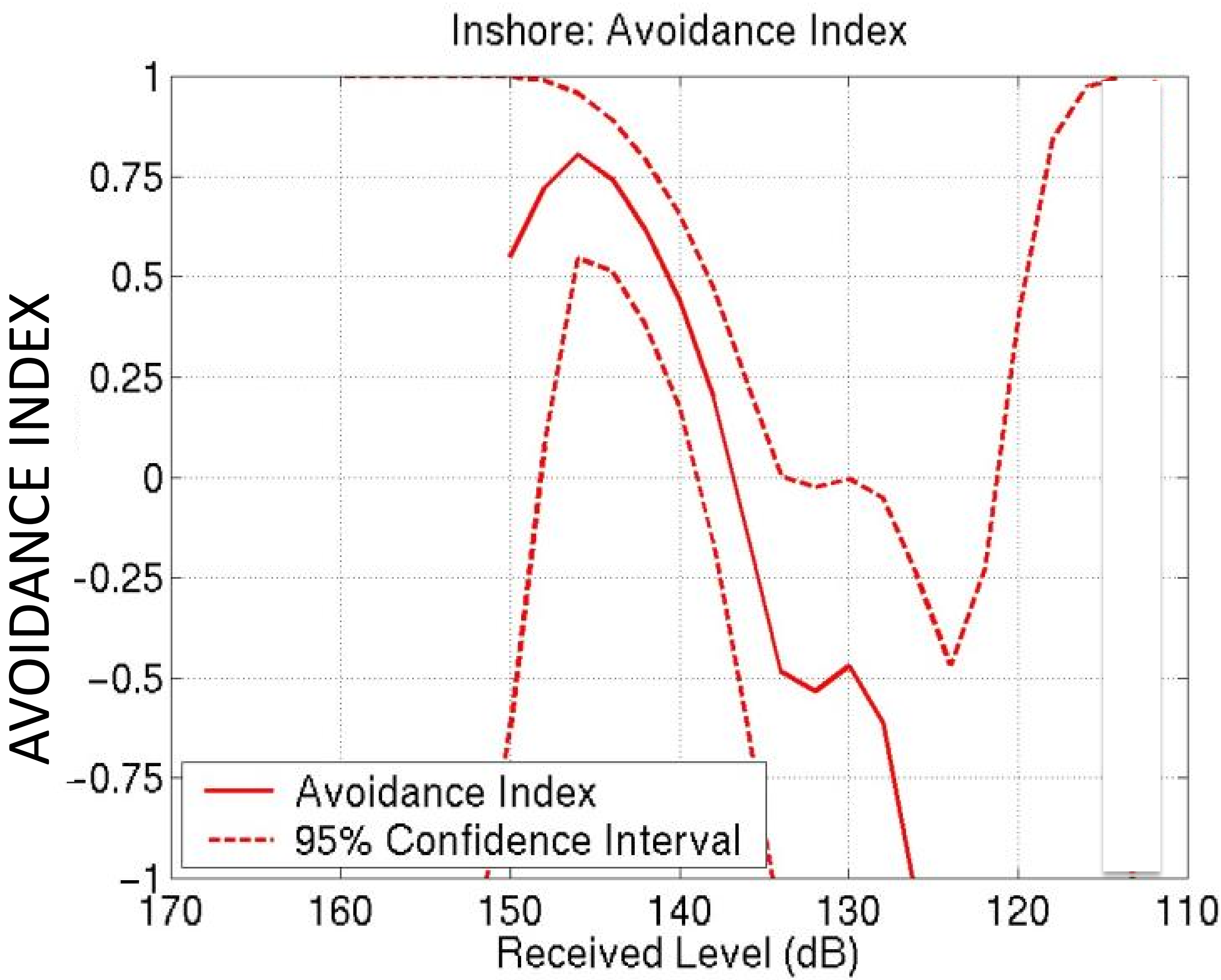


Control

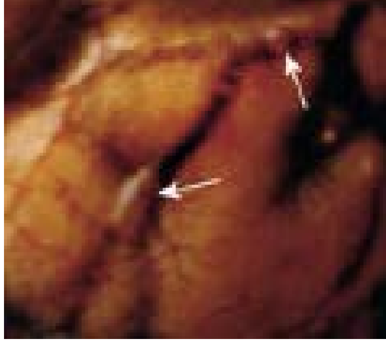


Whales avoid area near source

Avoidance of gray whales to LFA sonar increases at higher received levels



Example of need to discover unknown response

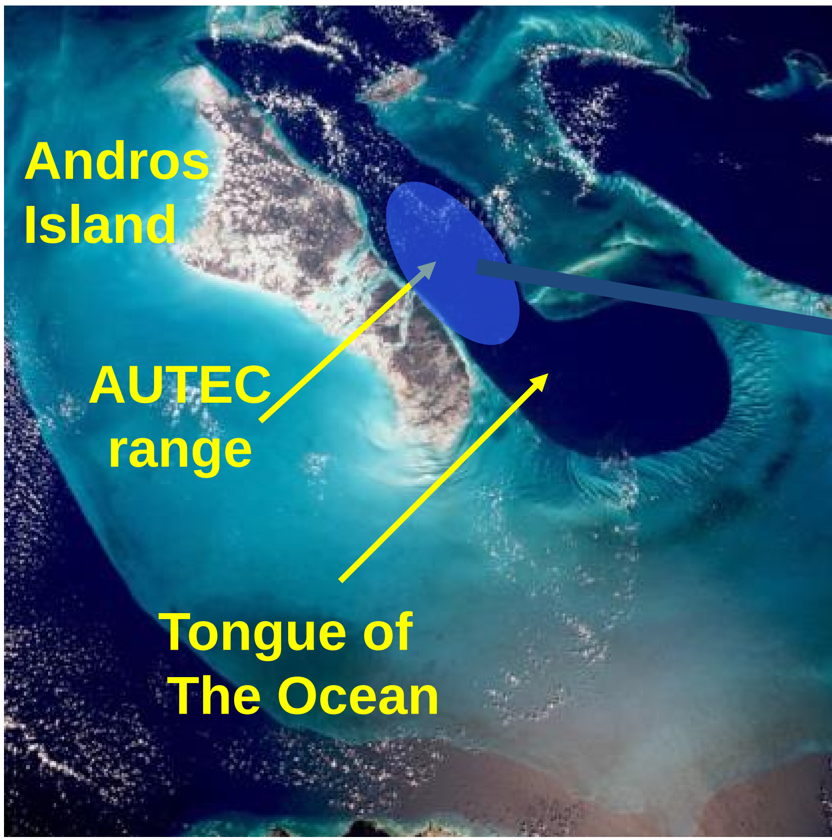


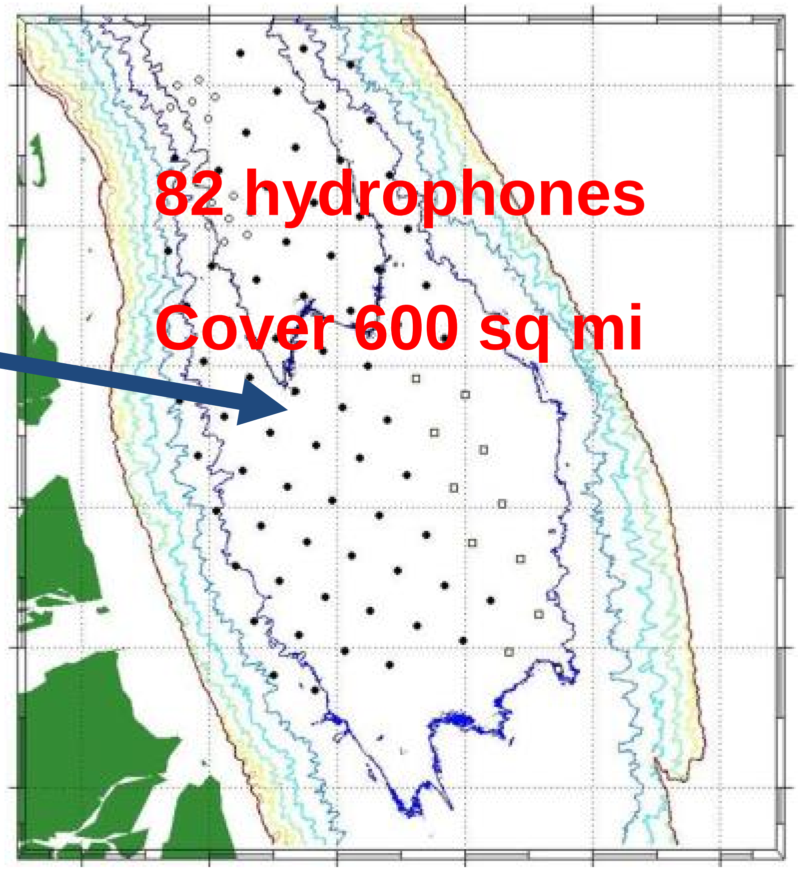
- By 2000 Bahamas report, US Navy and NMFS conclude that mid-frequency naval sonars can cause beaked whales to strand and die
- Cox et al. 2006 state mechanism is unknown, but a behavioral response likely initiates the process; top priority for CEEs to investigate behavioral and physiological responses (risk of DCS) that might start chain of events that results in stranding

BRS AUTEC study on Behavioral Responses of Beaked Whales to Experimental Playback of Sounds of Sonar vs a Predator

- Field work at Navy range where beaked whale sounds can be detected and located
- Use Dtag to record sound exposure and behavioral responses
- Deploy sound source from a stationary ship near tagged whale to transmit sounds when whales start clicking at depth
- Stop transmission as soon as whale stops clicking
- Use tag to monitor responses

Real time passive acoustic monitoring of beaked whales using AUTEC hydrophone array

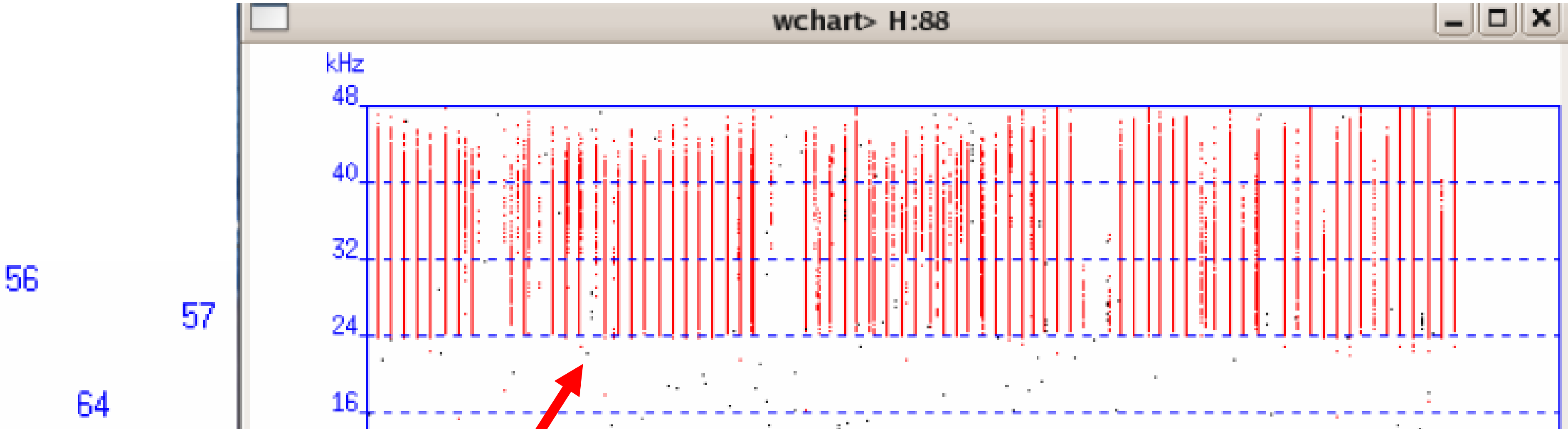




Collaboration with David Moretti, NUWC

NAVSEA NEWPORT Undersea Warfare Center Division

Marine Mammal Monitoring @ AUTEC

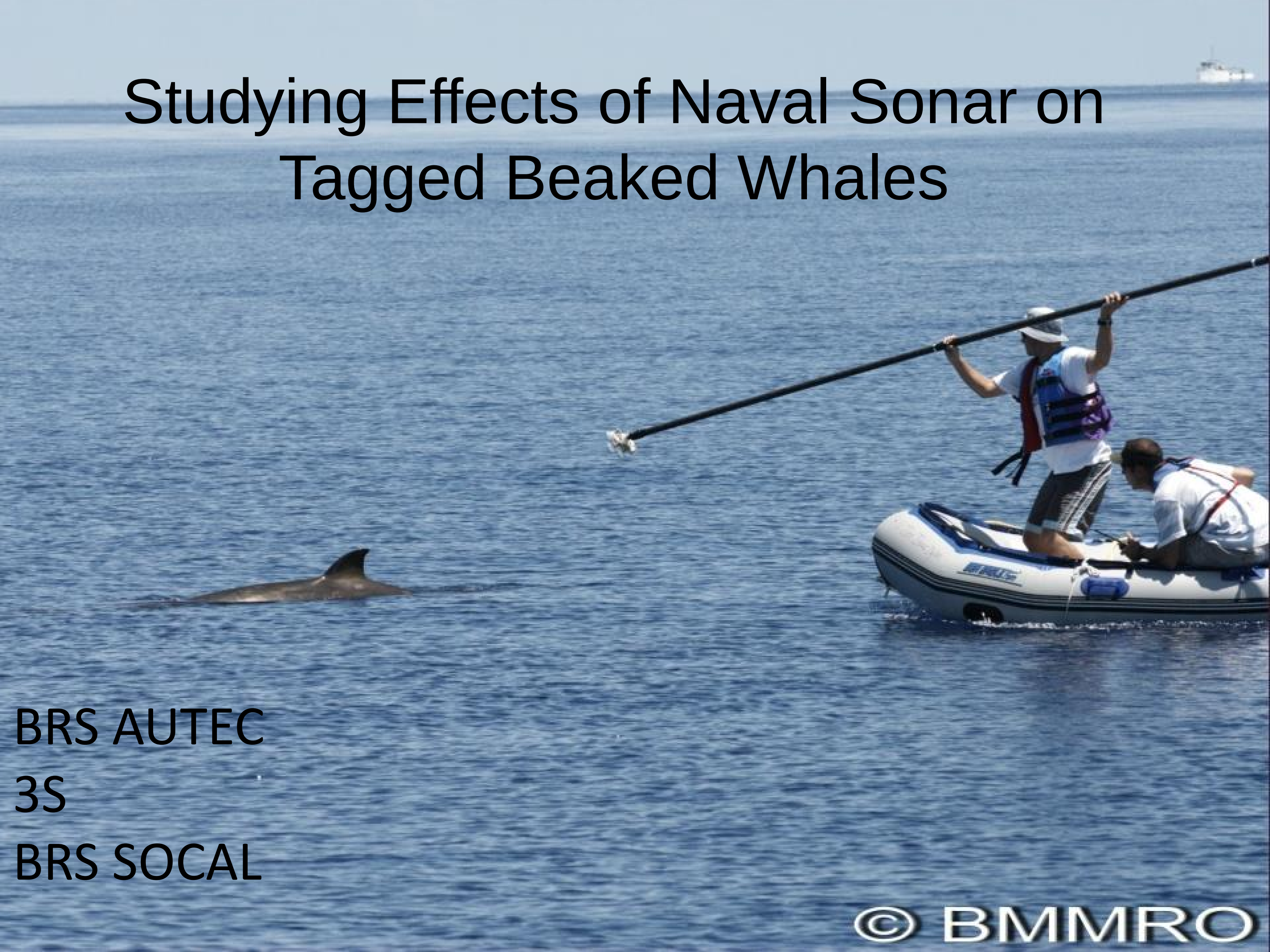


McCarthy et al. 2011

Experimental Contrasts

- STIMULI
  - **MFA**: mid-freq active sonar (actual 53C waveform)
  - **PRN**: pseudorandom noise with same timing and overall bandwidth as MFA
  - **ORCA**: Calls of mammal-eating killer whales
- SUBJECTS
  - Beaked whales
  - Other toothed whales with sonar-related strandings: Pilot whales, Melon-headed whales
  - Other toothed whales with no sonar-related strandings: False killer whales

Studying Effects of Naval Sonar on Tagged Beaked Whales

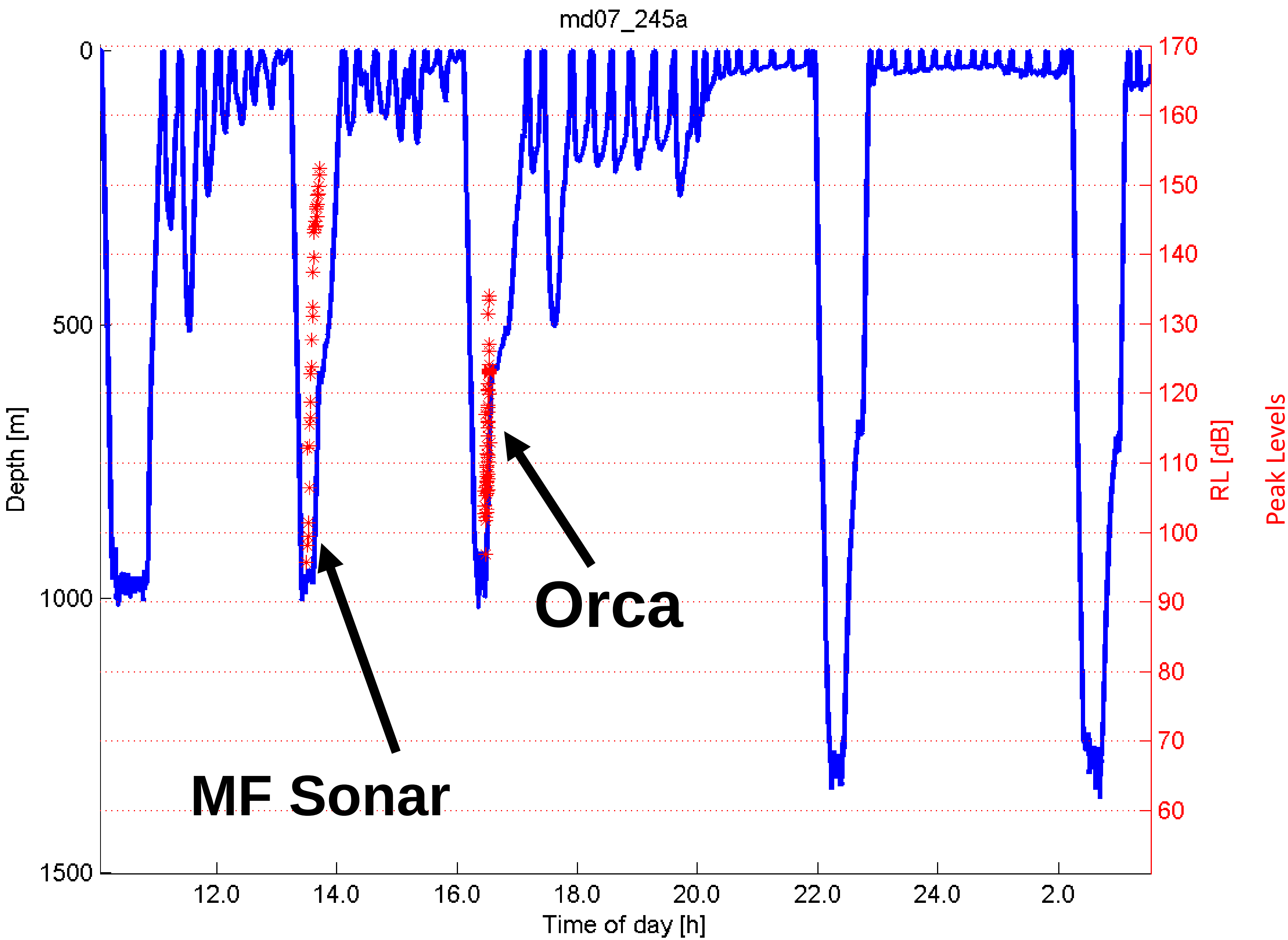


BRS AUTEC

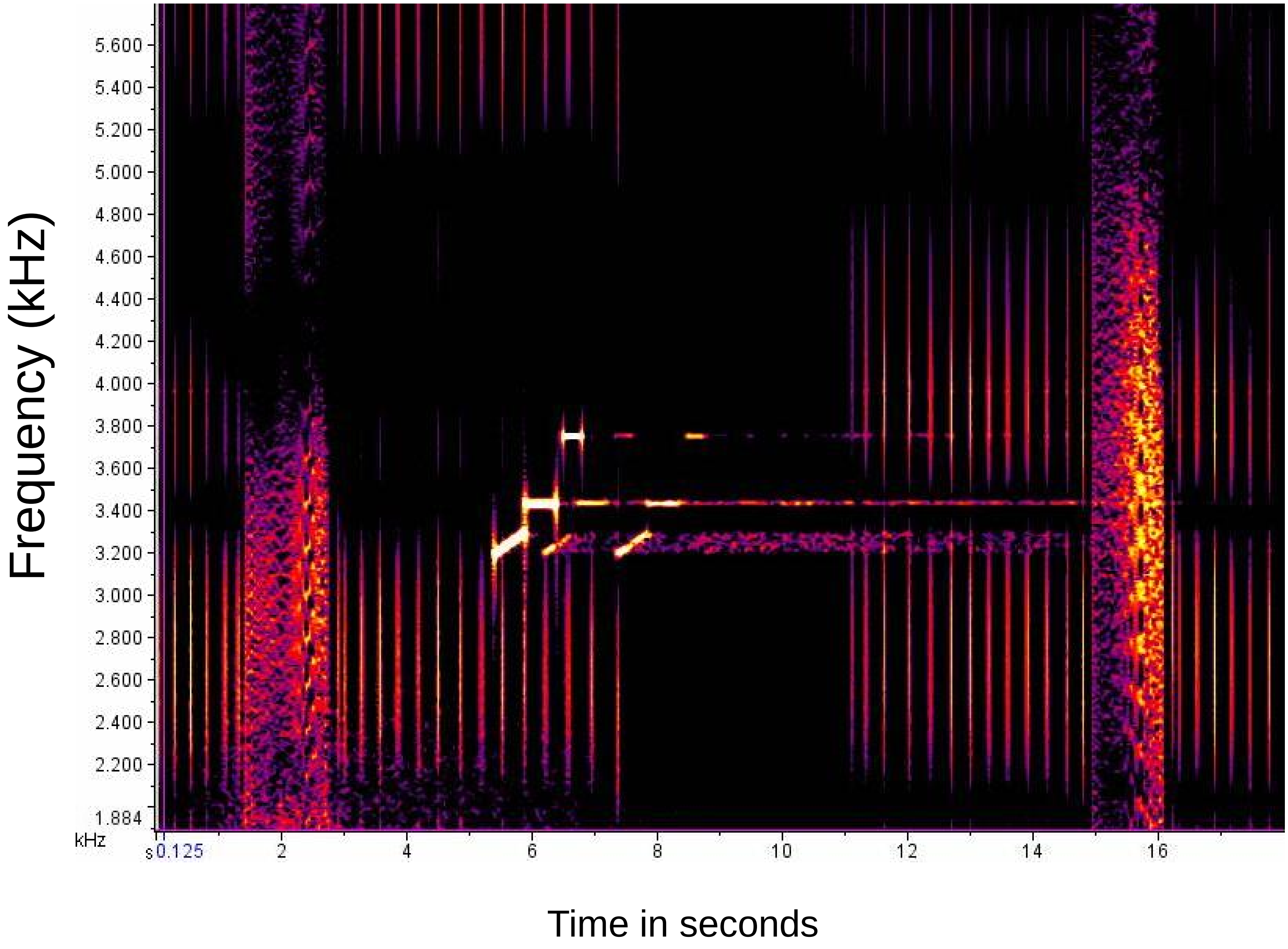
3S

BRS SOCAL

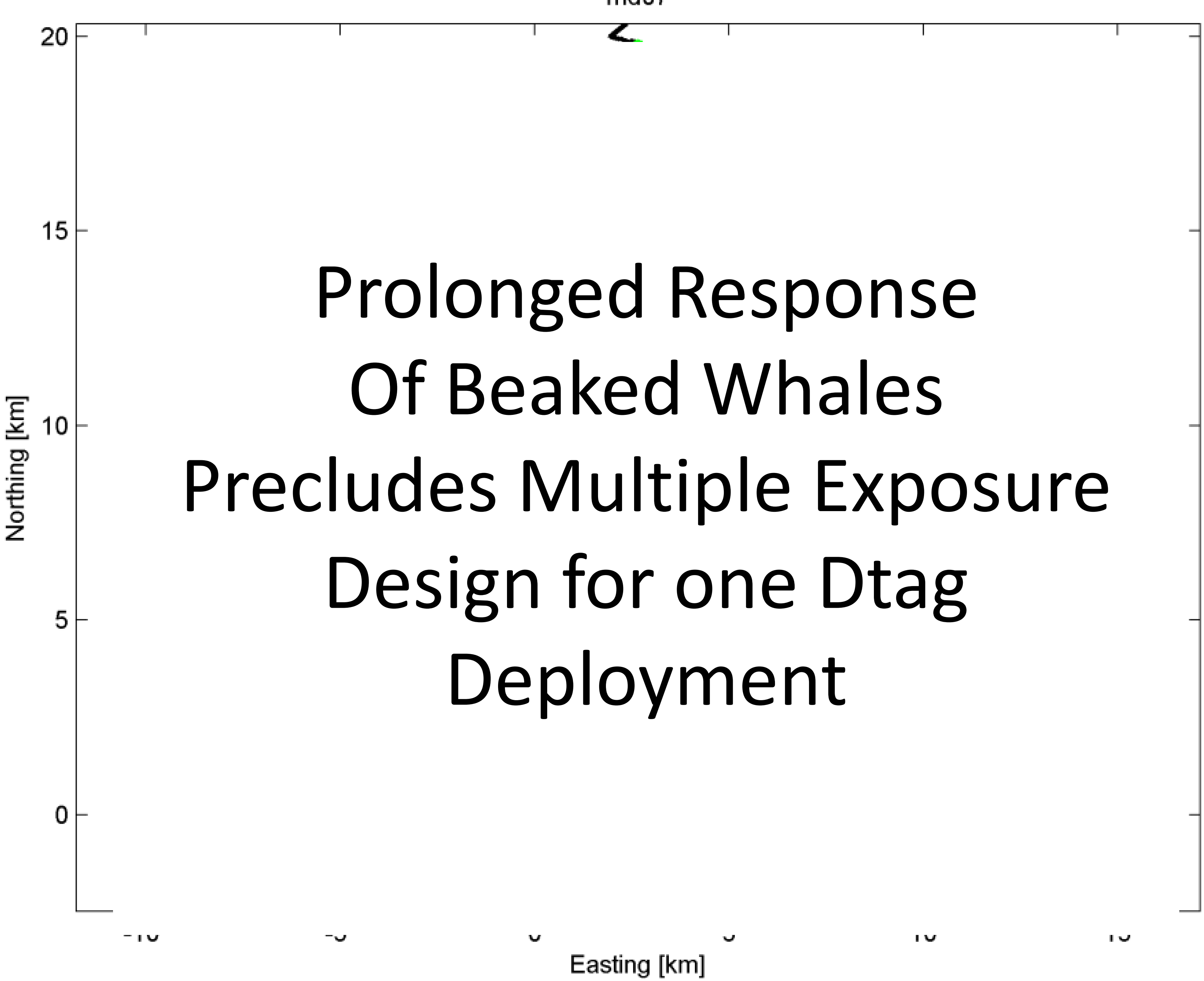
Received Level of Playbacks to *Mesoplodon densirostris*



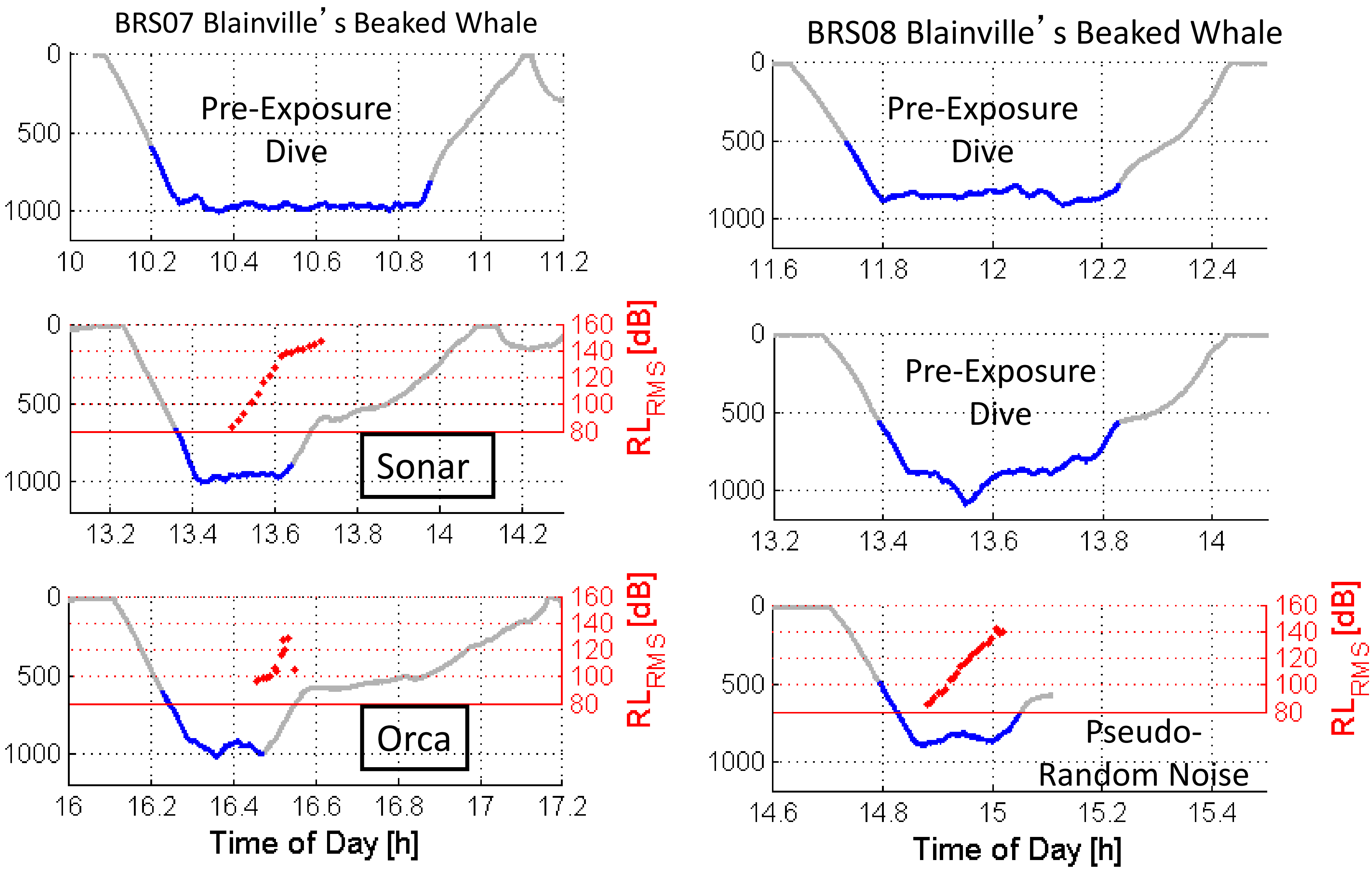
Naval Sonar as recorded on Dtagged Beaked Whale



Prolonged Response Of Beaked Whales Precludes Multiple Exposure Design for one Dtag Deployment

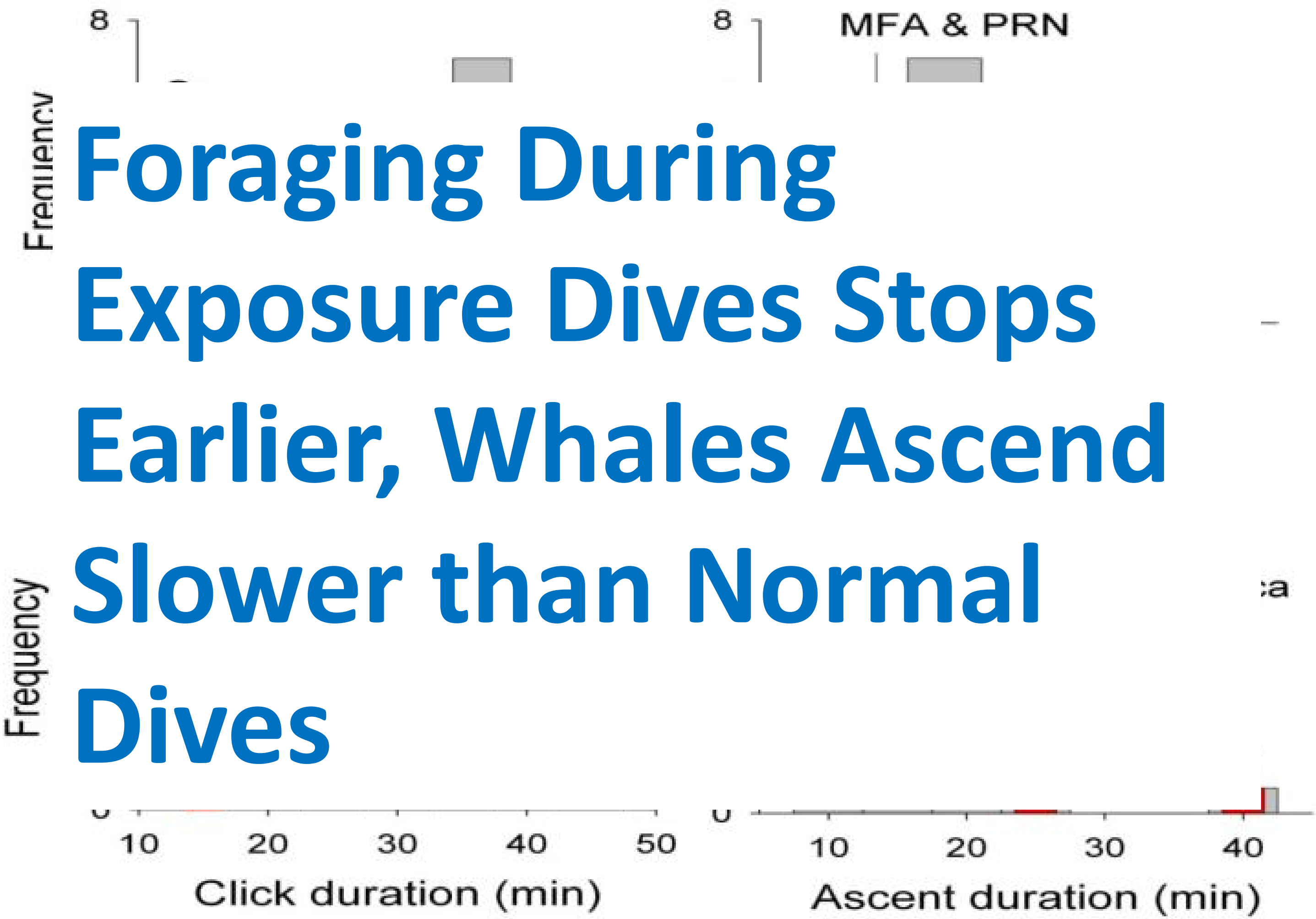


Beaked Whales exposed to Playback Prematurely Stop Clicking and Make a Long, Slow Ascent



Tyack et al. 2011

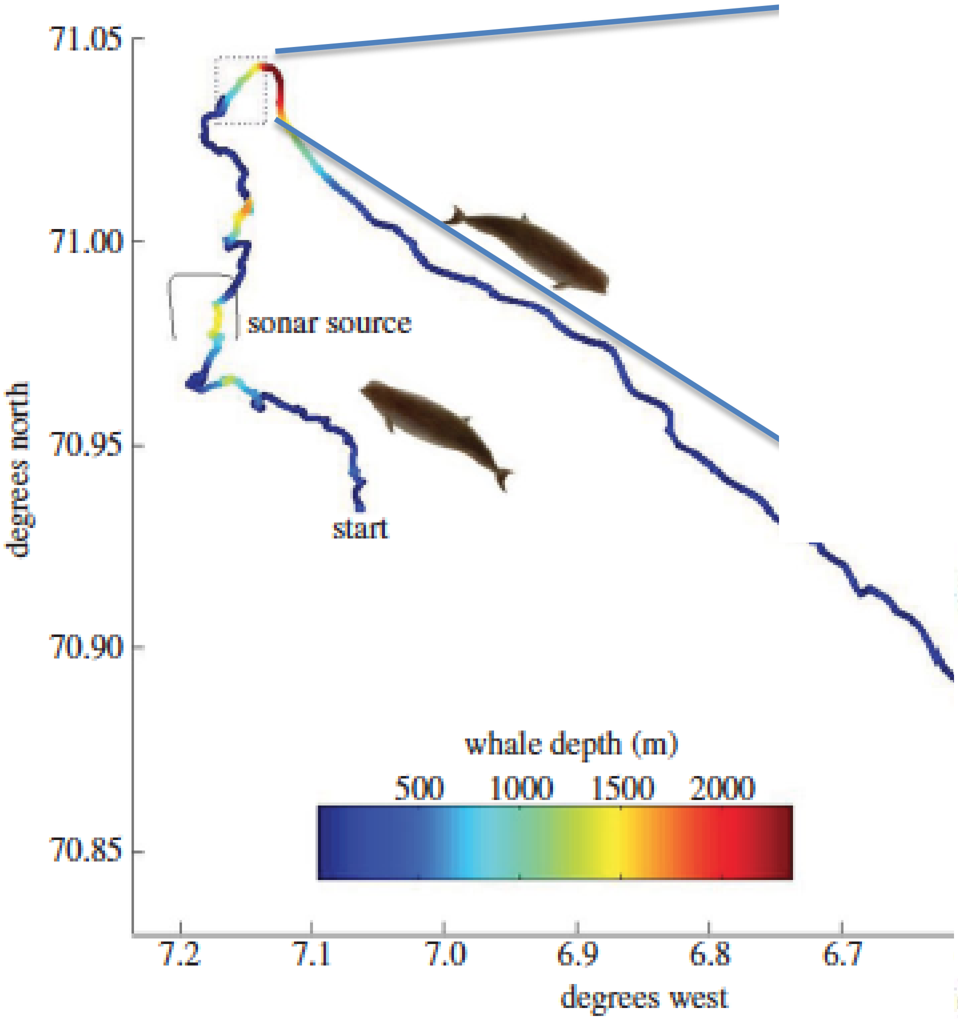
Because of large baseline dataset, statistically significant response to playback even with small N



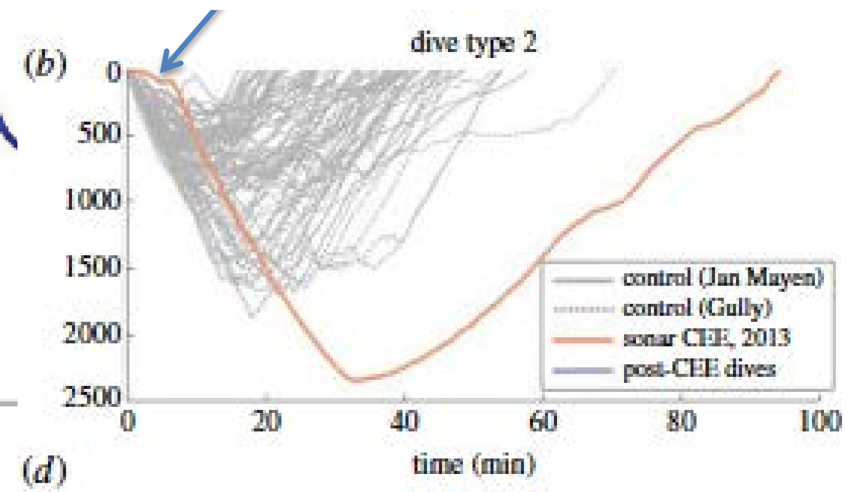
Foraging During Exposure Dives Stops Earlier, Whales Ascend Slower than Normal Dives

Tyack et al. 2011 PLoS ONE 6(3):e17009.

Bottlenose Whale Response to Sonar

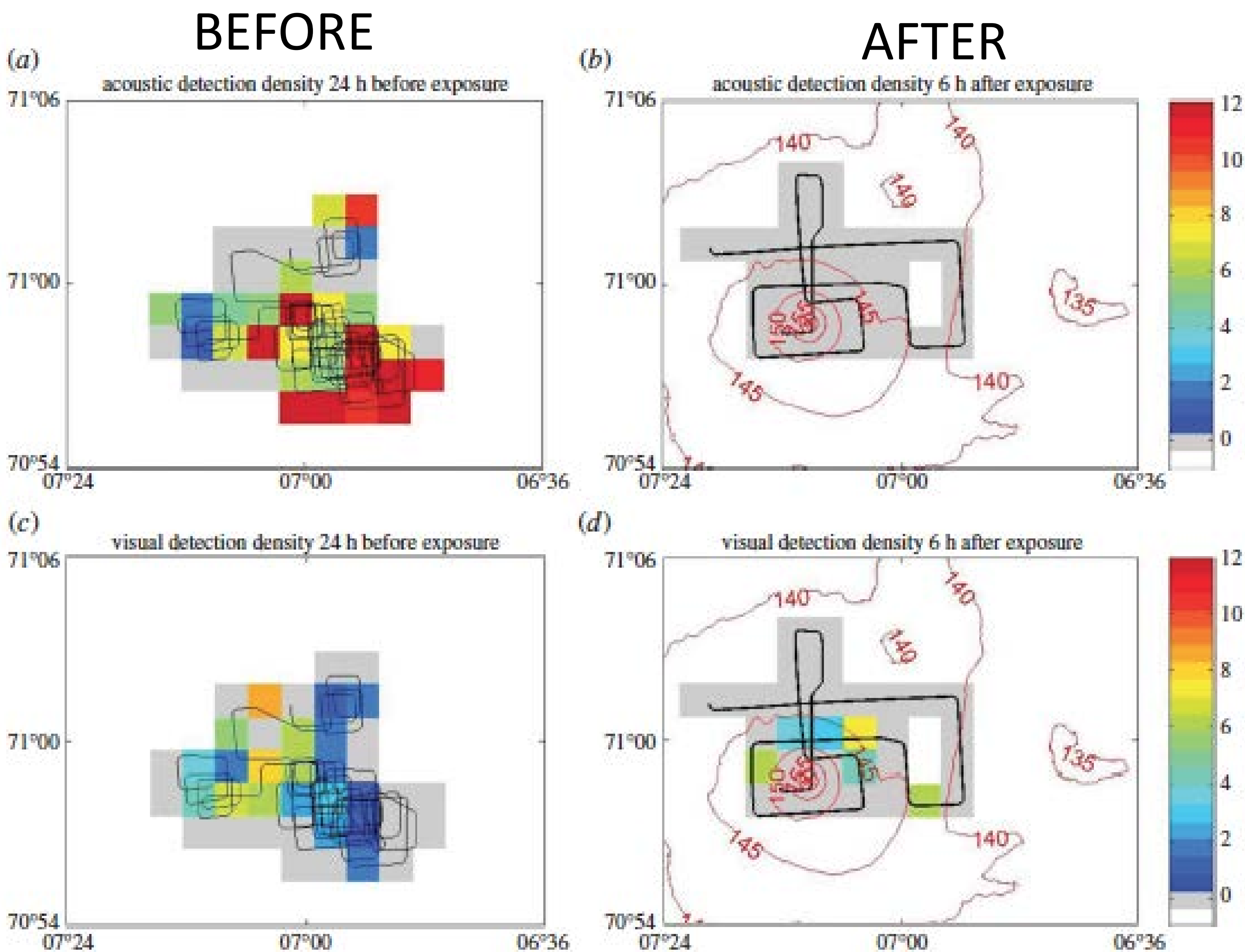


107 dB re 1 µPa of sonar exposure



Miller et al. (2015) R. Soc. Open Sci 2: 140484.

Few Bottlenose Whales Detected After Exposure



Miller et al. (2015) R. Soc. open sci 2: 140484.

Min Received Levels for Beaked Whale Response

Species	Stimulus	Received Level dB re 1 µPa rms broadband	Source
Mesoplodon densirostris 1	Orca	**97**	BRS AUTEC
Ziphius cavirostris 2	MFA	**98**	BRS SoCal
Hyperoodon ampullatus	MFA	**107**	3S
Ziphius cavirostris 3	MFA	**127**	BRS SoCal
Berardius bairdii	MFA	**127**	BRS SoCal
Ziphius cavirostris 1	Ship propulsion	**136**	Aguilar et al. (2006) Mar Mam Sci, 22(3): 690–699
Mesoplodon densirostris 1	MFA	**138**	BRS AUTEC
Mesoplodon densirostris 2	PRN	**142**	BRS AUTEC

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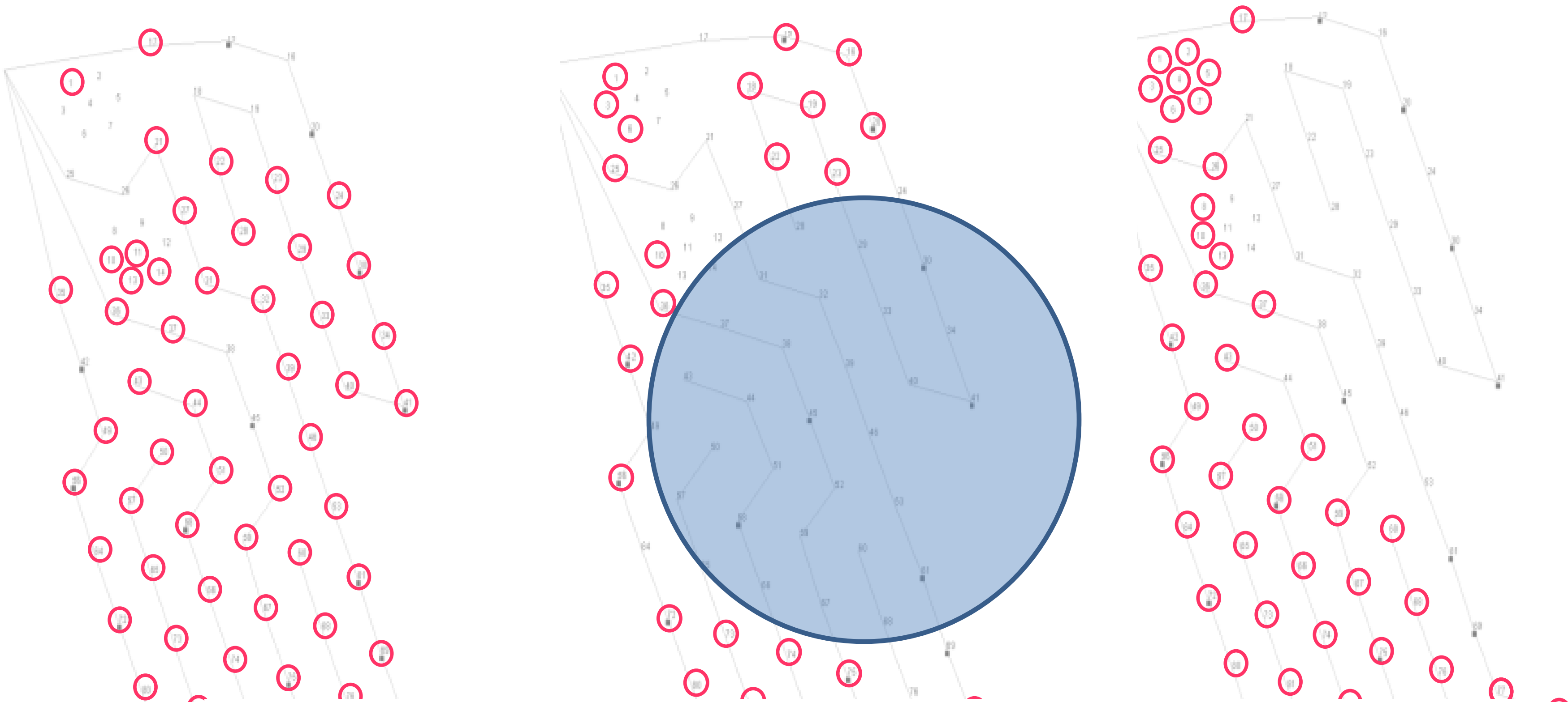
Distribution of Blainville's Beaked Whale Vocalizations Before, During, After Active Sonar Operations



EFFECT RANGE ~10 KM. CORRESPONDING RECEIVED LEVEL ~ 155 dB (235 – 20 log (10000))

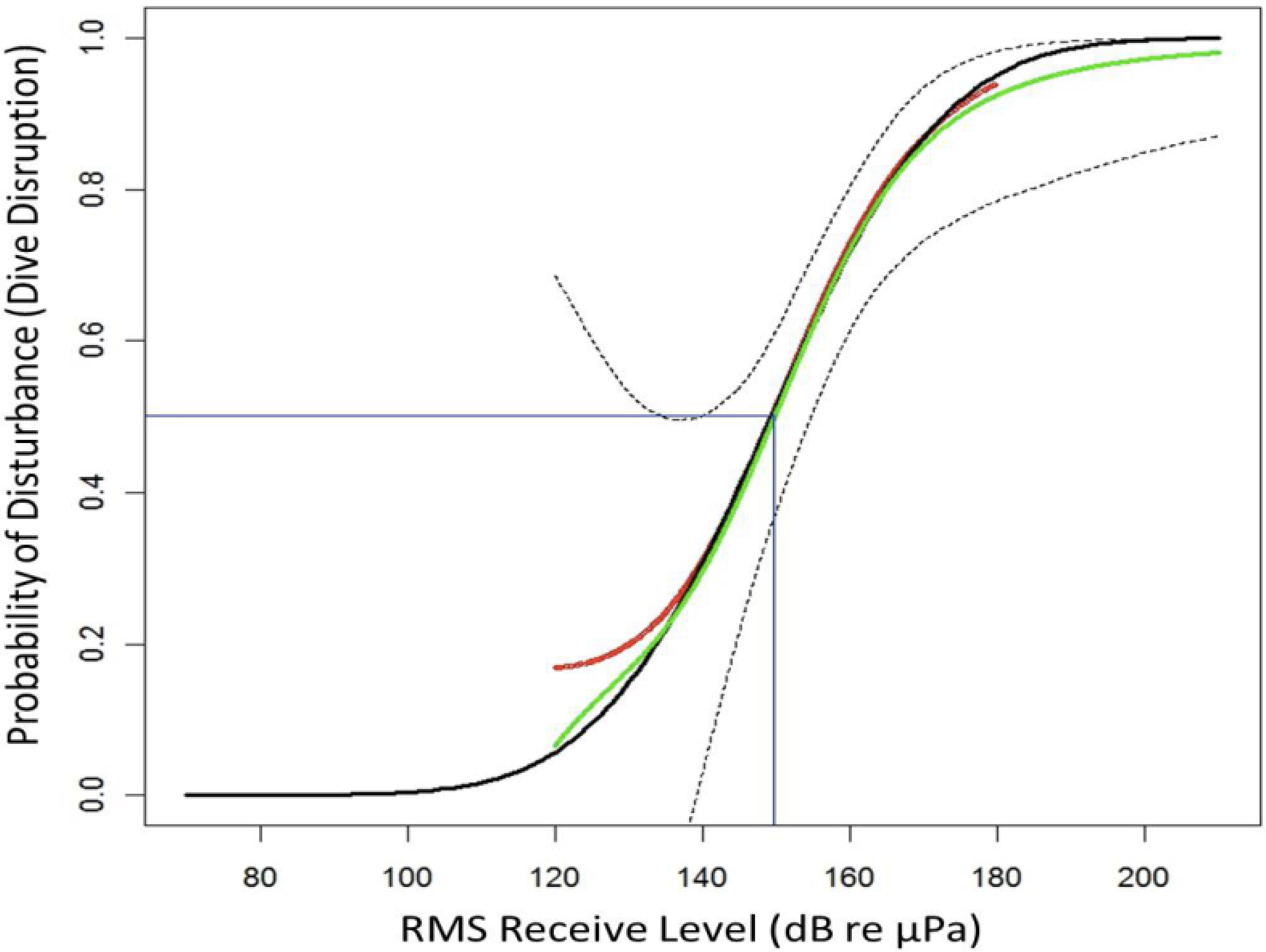
Record Duration= 19:39 hours:min
Groups on Range= 56
Vocal Duration (min)
Mean 32.56
Max 49
Min 11
Stand Dev 9.05

Record Duration= 22:56 hours:min
Groups on Range= 36
Vocal Duration(min)
Mean 20.42
Max 32
Min 2
Stand Dev 8.58

Record Duration= 22:01 hours:min
Groups on Range= 50
Vocal Duration (min)
Mean= 29.76
Max= 50
Min= 7
Stand Dev= 8.45

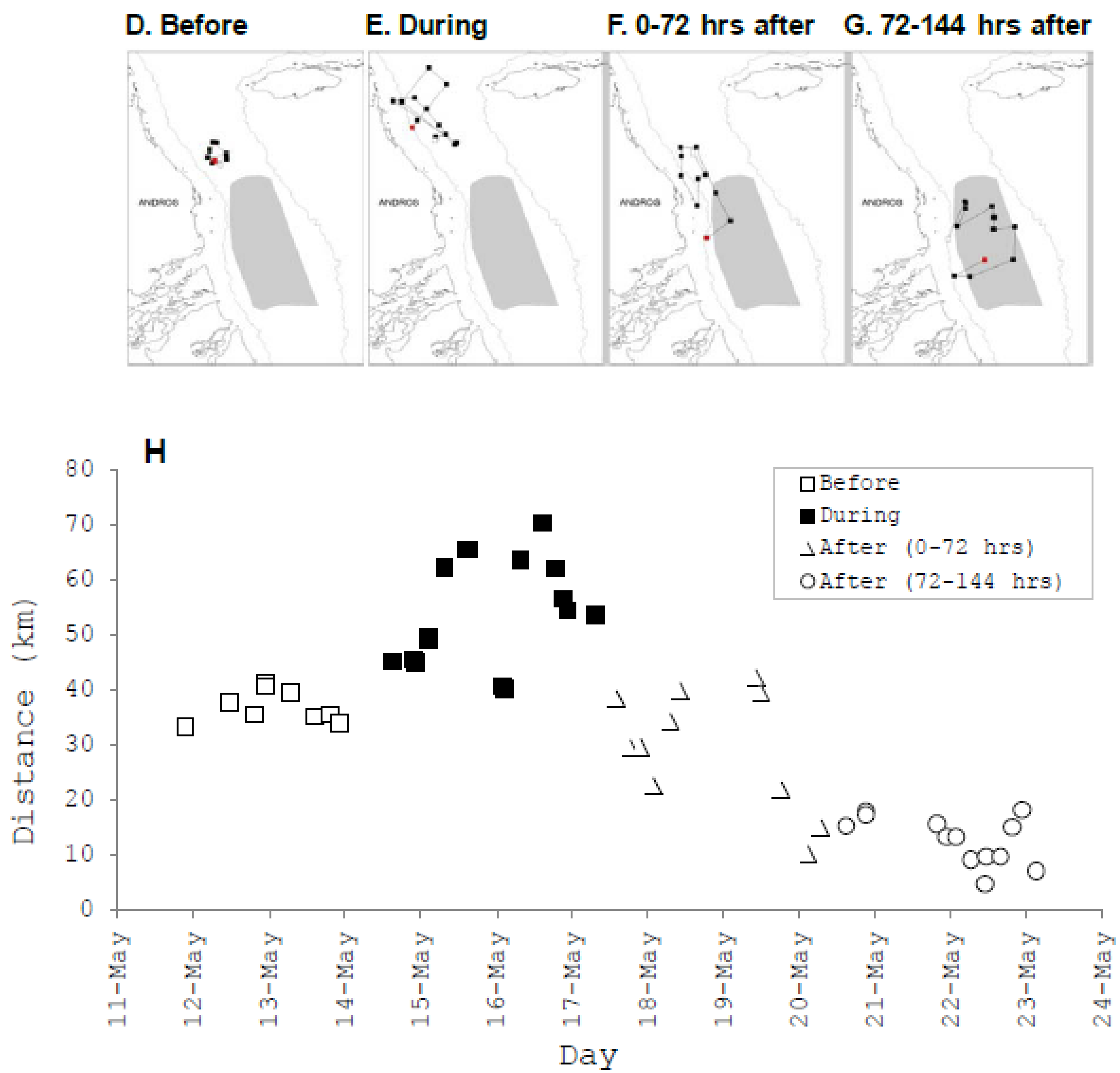
Tyack et al. 2011

Acoustic Dose:Disturbance Function for Blainville's Beaked Whale



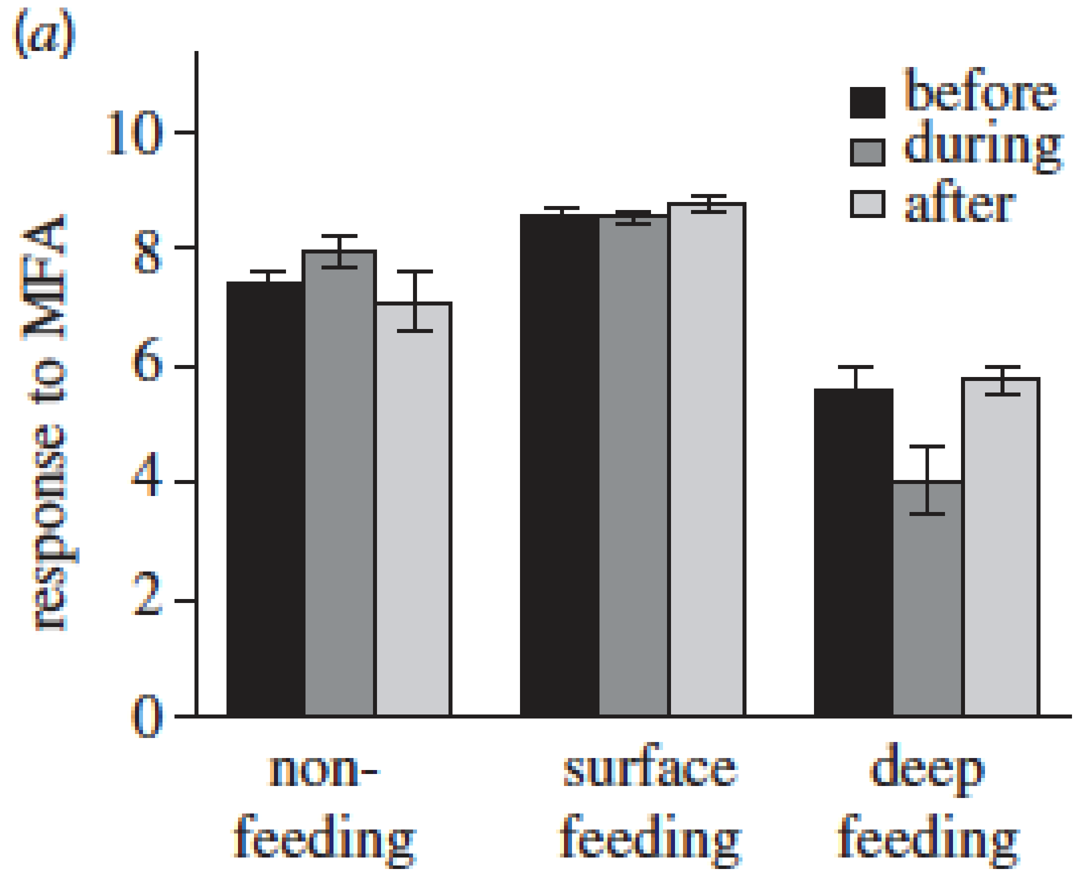
Moretti et al. 2014 PlosOne

Satellite Tag Tracks Response of Blainville's Beaked Whale to Sonar Exercise



Tyack et al. 2011

When Blue Whales Are Foraging Deep They Respond to Sonar By Avoidance and Cessation of Foraging



Goldbogen et al. 2013 Proc Roy Soc B

Transition path from CEE to monitoring

- Low sample size with behavior-and-sound recording tags, but they can quantify most potential responses along with exposure that elicited them
- Once responses are identified, either monitoring or lower data rate longer-term tags can build sample size
- Ultimate goal should be to use observed responses and dose:response functions to develop methods to monitor effects of actual operations and test predictions from dose:response functions
- Experiments remain essential for new species, new locations and new sonar signals

BRS Socal Photo taken under U.S. NMFS permit # 14534

Issues

- Especially in difficult to sight-and-tag or social species, subjects that can be tagged may be a biased sample of the population
- What are the appropriate parameters to characterize exposure for dose:response?
- How to pool across species and stimuli?
- How much does context need to be accounted for? If important, how to integrate into environmental assessments?
- Balance between regulatory needs and science: biological significance of responses

Censored Data Can be Used but Less Informative then Titrated

- If dose:escalation works correctly then you know the minumum exposure required to elicit response
- If animal responds on first ping, you know response threshold $\leq RL_{first}$
- If animal never responds during escalation, you know response threshold $> RL_{last}$

Min ⟵ Received Level ⟶ Max

Modeling Effects on Diving Physiology of Change in Dive Profiles During CEE Sonar Exposure

Kvadsheim et al. 2012 Frontiers

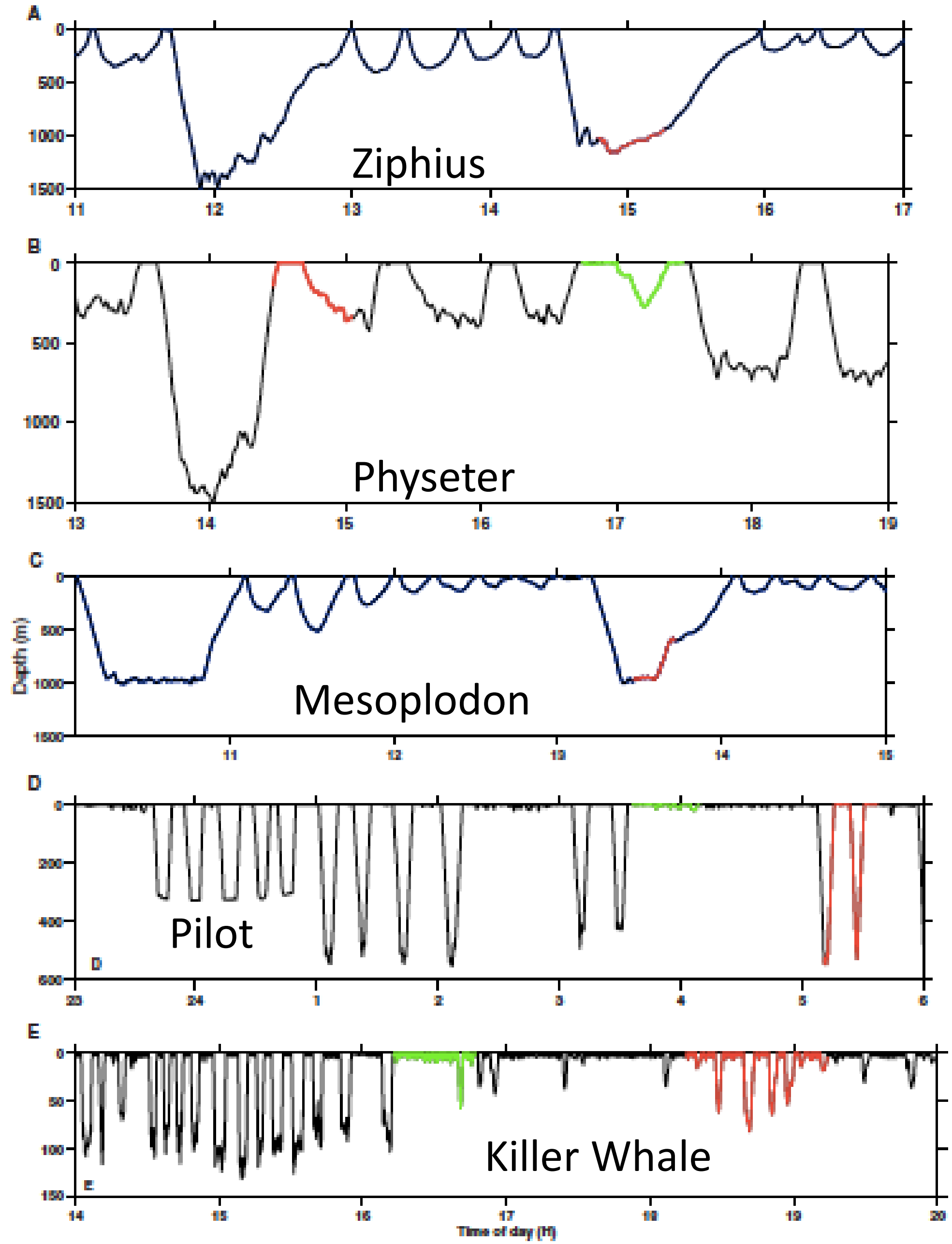
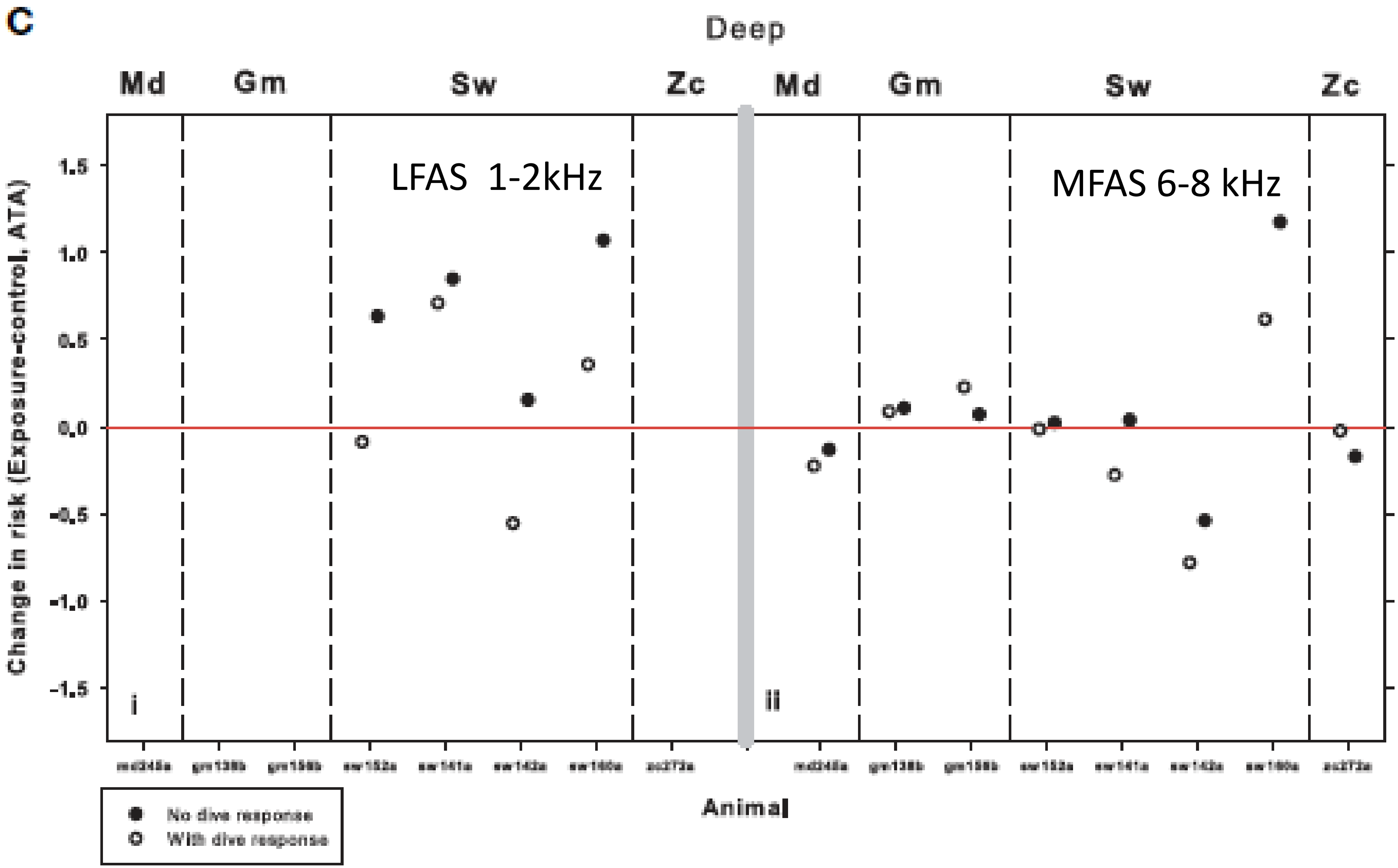


FIGURE 1 | Typical examples of changes in dive behavior in response to sonar. (A) Cuvier's beaked whale (zc10_272a), **(B)** sperm whale (sw09_160a), **(C)** Blainville's beaked whale (md07_245a), **(D)** pilot whale (gm09_156b), **(E)** killer whale (oo09_144a). The red part of the dive profile is exposure to MFAS sonar and the green to LFAS sonar. Time is in hours GMT and depth is in meters. Note the differences in depth scale between the different panels.

Dive Response to Sonar CEE can elevate DCS risk in sperm whales, but responses observed were safe



Kvadsheim et al 2012 Frontiers in Aquatic Physiology

Received Levels at beaked whales associated with premature cessation of foraging clicks

<table>
<tr><th>Species</th><th>Stimulus</th><th>Received Level</th><th>Source</th></tr>
<tr><td>Ziphius cavirostris 1</td><td>Ship propulsion</td><td rowspan="3">136-~140
dB re 1 μPa
rms broadband</td><td>Aguilar et al. (2006) Marine Mammal Science, 22(3): 690–699</td></tr>
<tr><td>Mesoplodon densirostris 2</td><td>Noise</td><td rowspan="3">Tyack et al. (2011) PlosOne 6(3): e17009</td></tr>
<tr><td>Mesoplodon densirostris 1</td><td>SONAR</td></tr>
<tr><td>Mesoplodon densirostris 1</td><td>Orca</td><td rowspan="3">97-102 dB re 1 μPa
rms broadband</td></tr>
<tr><td>Ziphius cavirostris 2</td><td>SONAR</td><td rowspan="2">DeRuiter et al. (2013) Biology Letters 9: 20130223</td></tr>
<tr><td>Ziphius cavirostris 3</td><td>SONAR</td></tr>
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