The Golden Age of Marine Mammal Behavioral Response Studies: Recent Progress and Paradigm Shifts in Evaluation and Mitigation

DOSITS Webinar – 16 March 2016

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* Historical Studies of Marine Mammal Behavioral Responses to Noise

* New Technologies - New Capabilities

* Recent Progress in Marine Mammal Behavioral Response Studies

* New Paradigms - Exposure Context & Broader Perspectives on Behavioral Disturbance
Conventional regulatory view

Single sound source

2-D sound “isopleths” with impacts based solely on exposure level “thresholds”

160 dB

180 dB
In reality, the ocean is full of many overlapping natural and human sound sources.

Real sound propagation highly variable.
Measuring Marine Mammal Behavior

• Experimental Methods
  - Controlled Exposure Experiments (CEEs) with FIELD and LAB BRS Approaches

• Observational/Oppportunistic Methods
  - Behavioral Monitoring during ongoing activities (uncontrolled)
Historical Experimental Studies of Marine Mammal Behavioral Response

During playbacks, bowheads tended to remain 400+ m (0.2 n.mi.) from projector. At that distance, received level ~115 dB re 1 μPa.

Richardson et al. (1991, 1995): OCS Studies MMS 91-0037 and 95-0051 (on BOEM website)
Historical Experimental Studies of Marine Mammal Behavioral Response

![Diagram](image-url)
Evolution of non-invasive, remote-deployed, archival tags to obtain high-resolution, multivariate individual data

- **Depth** (pressure sensors)
- **3D movement** (accelerometers, magnetometers)
- **Light** (photo sensors)
- **High-sampling rate acoustics** (up to 512 kHz; multiple hydrophones)
- **Lat/Lon position**
Quantifying Behavior & Responses: Technological Innovations

Identifying Vocalizing Individuals (Response, Density Estimates)

Accelerometers to identify calling fin whales (Goldbogen et al., 2014)

Time of arrival differences to identify clicking Risso’s dolphins (Arranz et al., in review)
Quantifying Behavior & Responses: Technological Innovations

BEHAVIORAL CONTEXT: Synoptic, Direct Measurements of Prey for Feeding Animals

- Five-fold increase in ability to describe variance in behavior in CEEs

(Goldbogen et al., 2014; Friedlaender et al., 2016)
Recent Progress in Marine Mammal Behavioral Response Studies

Bahamas (AUTEC): 2007-2008

- US Navy/NOAA coordinated BRS to obtain direct data on responses of cetaceans (including beaked whales) to the tactical mid-frequency sonars involved in previous stranding events.
Recent Progress in Marine Mammal Behavioral Response Studies

3S Program (Norway): 2007-present
- Dutch/Norwegian collaboration to measure responses to operational Navy sonars
- Operational, mobile sources approach subjects to increase dose

Miller et al., 2012; 2014; Cure et al., 2013; Wensveen et al., 2015; Isojunno et al., 2016
Recent Progress in Marine Mammal Behavioral Response Studies

BRAHHS Program (Australia): 2010-present

- Australian collaboration to measure potential behavioral responses and significance for migrating humpback whales to seismic airgun surveys
- High sample sizes, careful controls, different exposure conditions (small airgun, ramp-up, full airgun array)

Single airgun BRS

- Decreases in dive time and southbound migration during exposure
- Effect not correlated with source distance, RL, source direction, or exposure time
- Orienting responses to source vessel

Dunlop et al., 2015; 2016

Recent Progress in Marine Mammal Behavioral Response Studies

Southern California (SOCAL) BRS: 2010-present

- > 175 tags deployed on 10 species; 80 CEEs using simulated and actual Navy sonar

- Variables (beyond received level): Behavioral state, prey distribution, spatial orientation/movement

- Responses: avoidance; changes in diving, feeding, social

- Certain species (beaked whales) appear particularly sensitive; other species are more tolerant but variable depending on exposure context

Southall et al., 2012; 2014; 2015; De Ruiter et al., 2013; Goldbogen et al, 2013; Friedlaender et al., 2016
**Recent Progress in Marine Mammal Behavioral Response Studies**

Southern California (SOCAL) BRS: 2010-present

Contextual aspects of exposure (e.g., behavioral state, prey distribution, relative proximity) can be as or more important than received level

Goldbogen et al, 2013; Friedlaender et al., 2016; Southall et al., in prep;
On beyond thresholds...

A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds

W.T. Ellison,* B.L. Southall,† C.W. Clark,§ and A.S. Frankel*
Species differences in response probability exist, with some particularly sensitive species (e.g., beaked whales, harbor porpoise, melon-headed whales)

Received level is one of many exposure contextual factors (behavioral state, exposure-animal proximity)
- Don’t have to measure every possible contextual combination

Quantitative exposure estimates can be improved using probabilistic movement models that incorporate behavior
New Paradigms - Exposure Context & Broader Perspectives on Behavioral Disturbance

• Ultimately the severity and consequences of response matter most, not just exposure or discrete response (PCOD)

• Exposure (“take”) estimates must be put into biologically-meaningful, real-world context – risk assessment

• Exposure-response analyses in regulatory processes must incorporate new paradigms of response complexity and consequence; mitigation measures must remain simple
ACKNOWLEDGMENTS

RESEARCH PROGRAMS