New developments in research and technology to study marine mammal behavior and the effects of human noise

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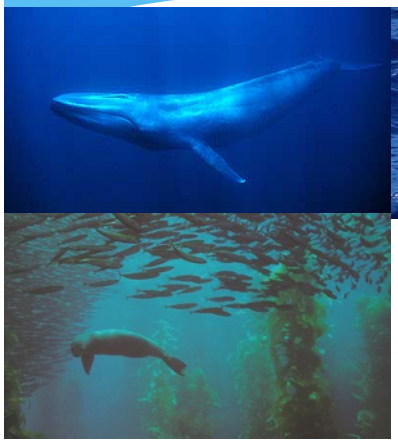
Marine Animal Acoustics and Anthropogenic Noise



Marine animals produce sound and listen for environmental acoustic cues. Underwater sound is critical in life history

For many of the same physical reasons, humans produce underwater sound either *intentionally* or *incidentally*

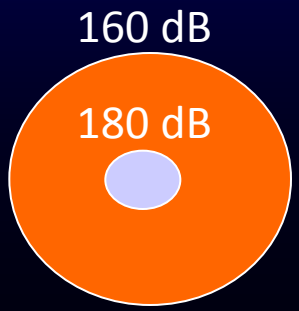
WHEN IS ANTHROPOGENIC SOUND A THREAT TO MARINE LIFE?

WHAT CAN BE DONE TO MITIGATE IMPACTS OF ACTIVITIES VITAL TO NATIONAL & ECONOMIC SECURITY?

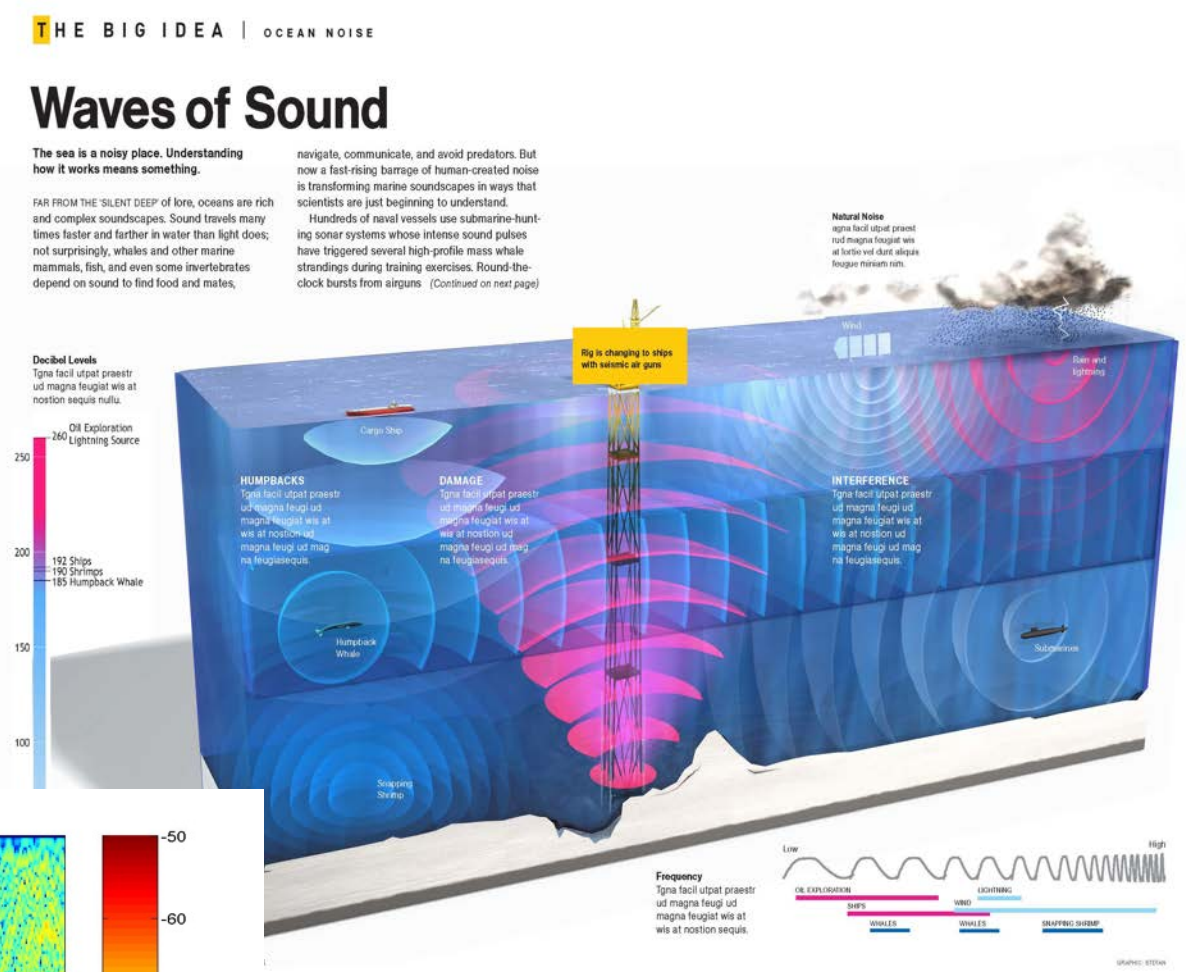
Conventional regulatory view

Single sound source

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



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



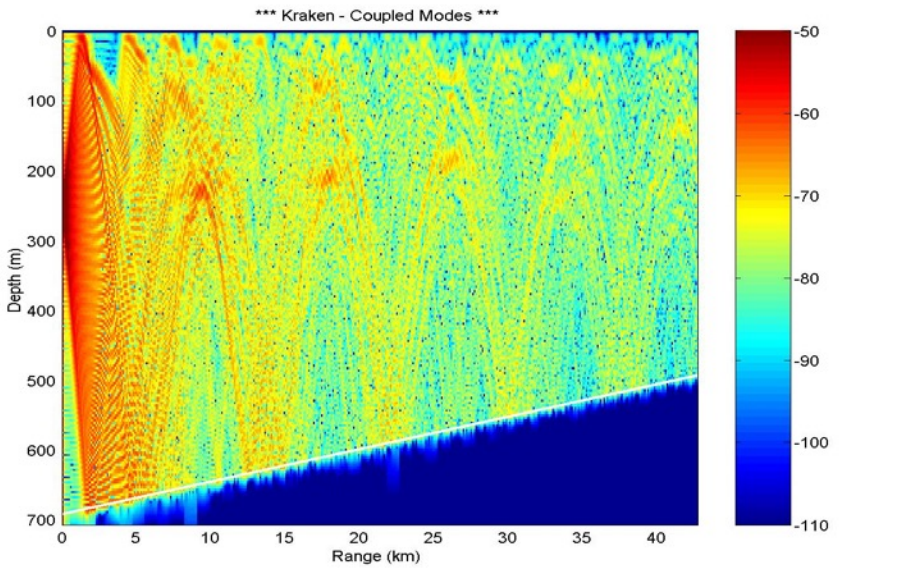
THE BIG IDEA | OCEAN NOISE

Waves of Sound

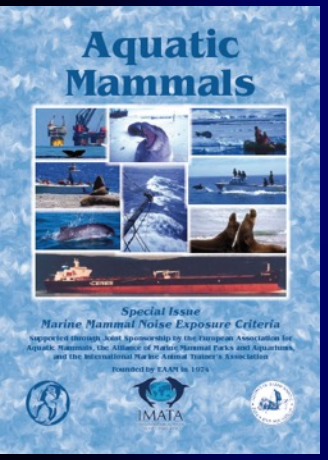
The sea is a noisy place. Understanding how it works means something.

FAR FROM THE 'SILENT DEEP' of lore, oceans are rich and complex soundscapes. Sound travels many times faster and farther in water than light does; not surprisingly, whales and other marine mammals, fish, and even some invertebrates depend on sound to find food and mates, navigate, communicate, and avoid predators. But now a fast-rising barrage of human-created noise is transforming marine soundscapes in ways that scientists are just beginning to understand.

Hundreds of naval vessels use submarine-hunting sonar systems whose intense sound pulses have triggered several high-profile mass whale strandings during training exercises. Round-the-clock bursts from airguns (Continued on next page)



Real sound propagation highly variable



Effects of Noise on Marine Life

- None observable
- Interference with Communication
  - Auditory masking (loss of acoustic “habitat”)
  - *Temporary or permanent hearing damage*
- Behavioral Responses
  - Orientation, increased alertness, vocal changes
  - Effects on feeding, social activity, risk of predation
  - Habitat abandonment: temporary or *permanent*
- Physiological Effects (stress, DCS)
- *Stranding causing injury or death*

Generally Increasing Severity

but

Generally Decreasing Occurrence

Measuring Marine Mammal Behavior

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

- Observational/Opportunistic Methods
  - *Behavioral Monitoring* during ongoing activities (uncontrolled)

Measuring cetacean responses to military sonar: *Southern California Behavioral Response Study (SOCAL-BRS)*

Photo taken under U.S. NMFS permit # 14534

Field Behavioral Response Studies: Key Technological Innovation

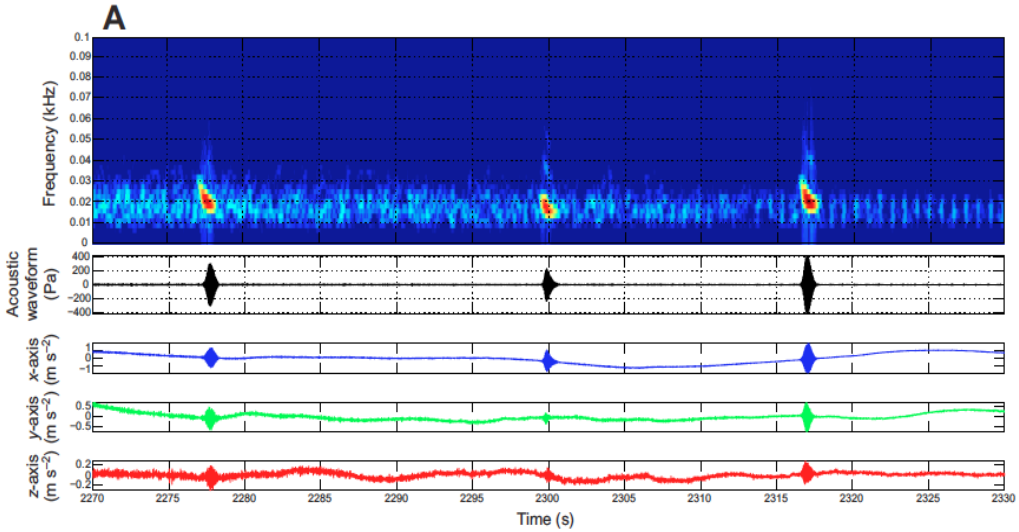
Evolution of **non-invasive, remote-deployed, archival tags** to obtain high-resolution, multivariate individual data

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

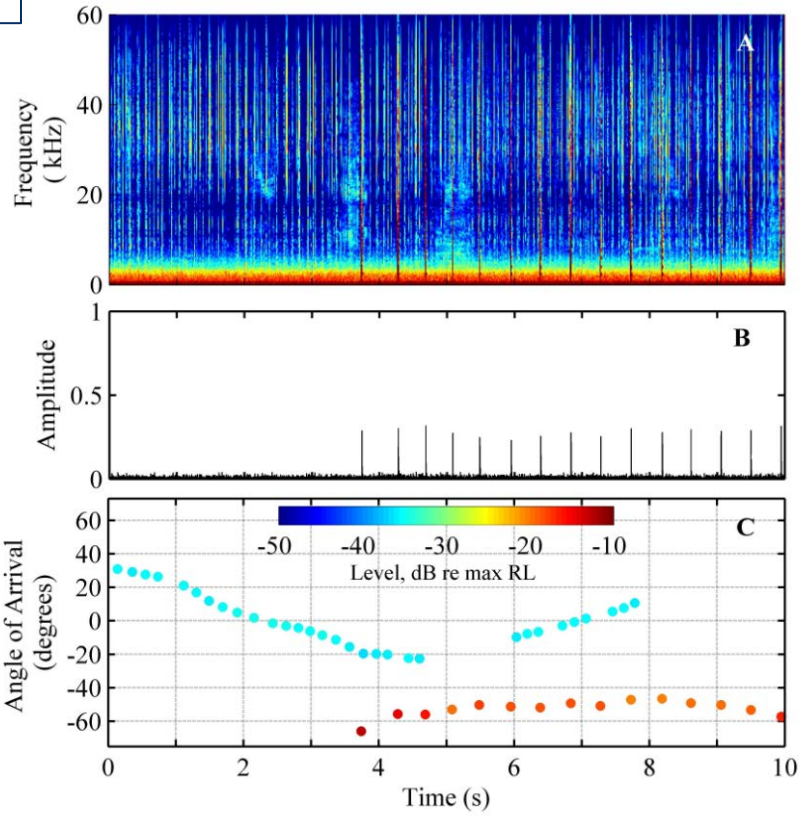
Quantifying Behavior & Responses: SOCAL-BRS Technological Innovations

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*)



SOCAL-BRS: Overall Approach

- Acoustic tags and controlled exposures (A-B-A) to measure baseline behavior and changes
- Adapt multidisciplinary approach to new species (Southall *et al*., 2012)
- Maximize flexibility re: weather and animals

PAPER

Marine Mammal Behavioral Response Studies in Southern California: Advances in Technology and Experimental Methods

Decentralized Vessel Strategy:

* Smaller, flexible central platform
* Fast, independent tag boats
* Fixed range off SCI and towed passive acoustics
* Real Navy ships at real ranges

SOCAL-BRS: Experimental Phases

Exposure
(*During* CEE)

- Explicit start-up, exposure, shutdown protocols
- Visual survey and focal follow maintained
- Scaled source (MFA/PRN)
- *Real Navy MFA* (53C)

Pre-exposure
(*Before* CEE)

- Animal(s) tagged
- Focal follow (RHIB)
- Scaled source ~ 1km
- Navy ship range modeled

Photo taken under U.S. NMFS permit # 14534

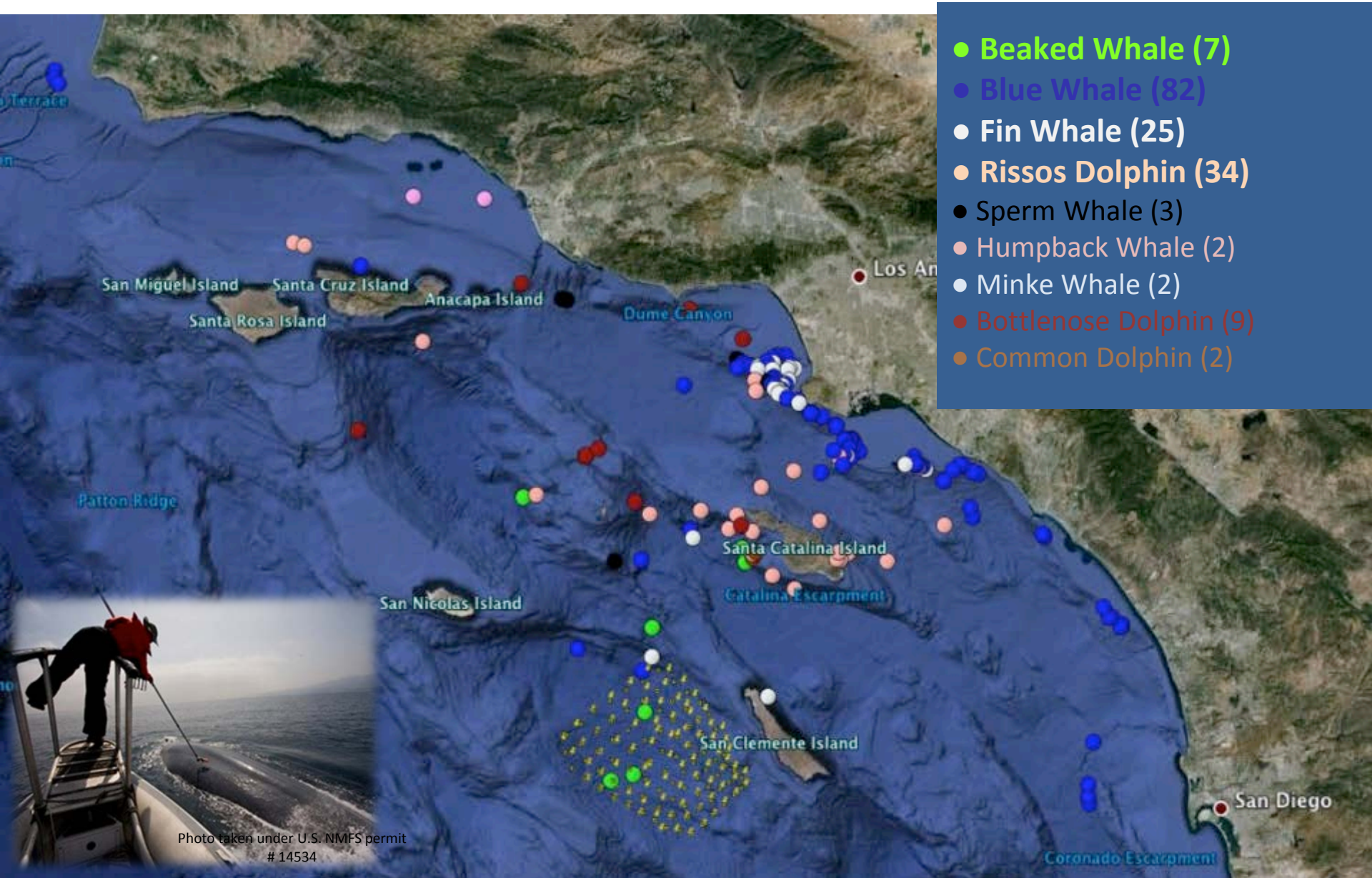
Post-exposure
(*After* CEE)

-Visual survey, focal follow
- Source vessel ~1km
- Navy ship range modeled
- VHF tracking of tags

livingmarine RESOURCES

TECHNICAL PROGRESS: ALL TAG DEPLOYMENTS (2010-15)

- **Beaked Whale (7)**
- **Blue Whale (82)**
- **Fin Whale (25)**
- **Rissos Dolphin (34)**
- Sperm Whale (3)
- Humpback Whale (2)
- Minke Whale (2)
- Bottlenose Dolphin (9)
- Common Dolphin (2)



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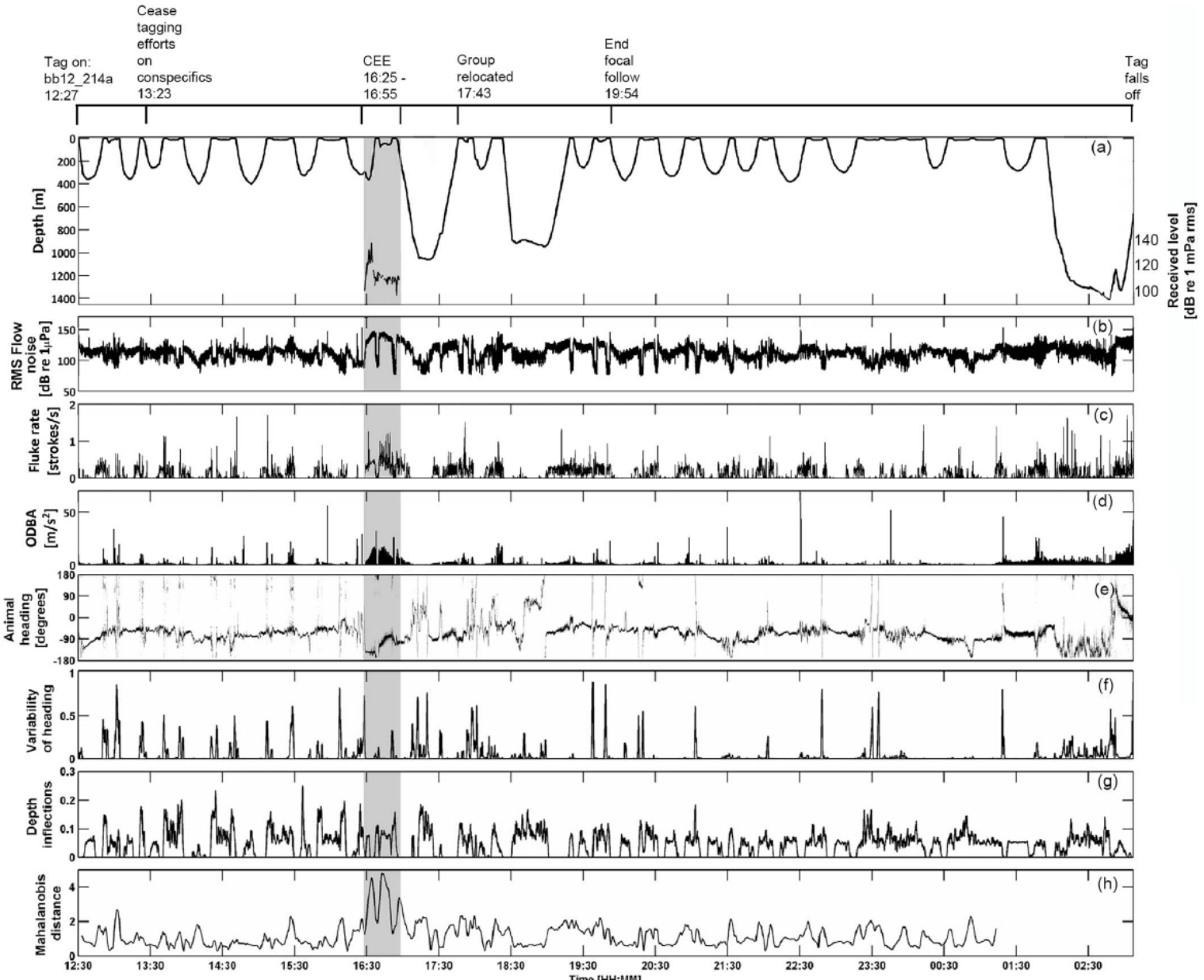
SOCAL-BRS: BEAKED WHALES (BAIRD'S SCALED MFA)

Stimpert *et al.*, (2014)



SOCAL-BRS: BEAKED WHALES (CUVIER'S SCALED MFA)

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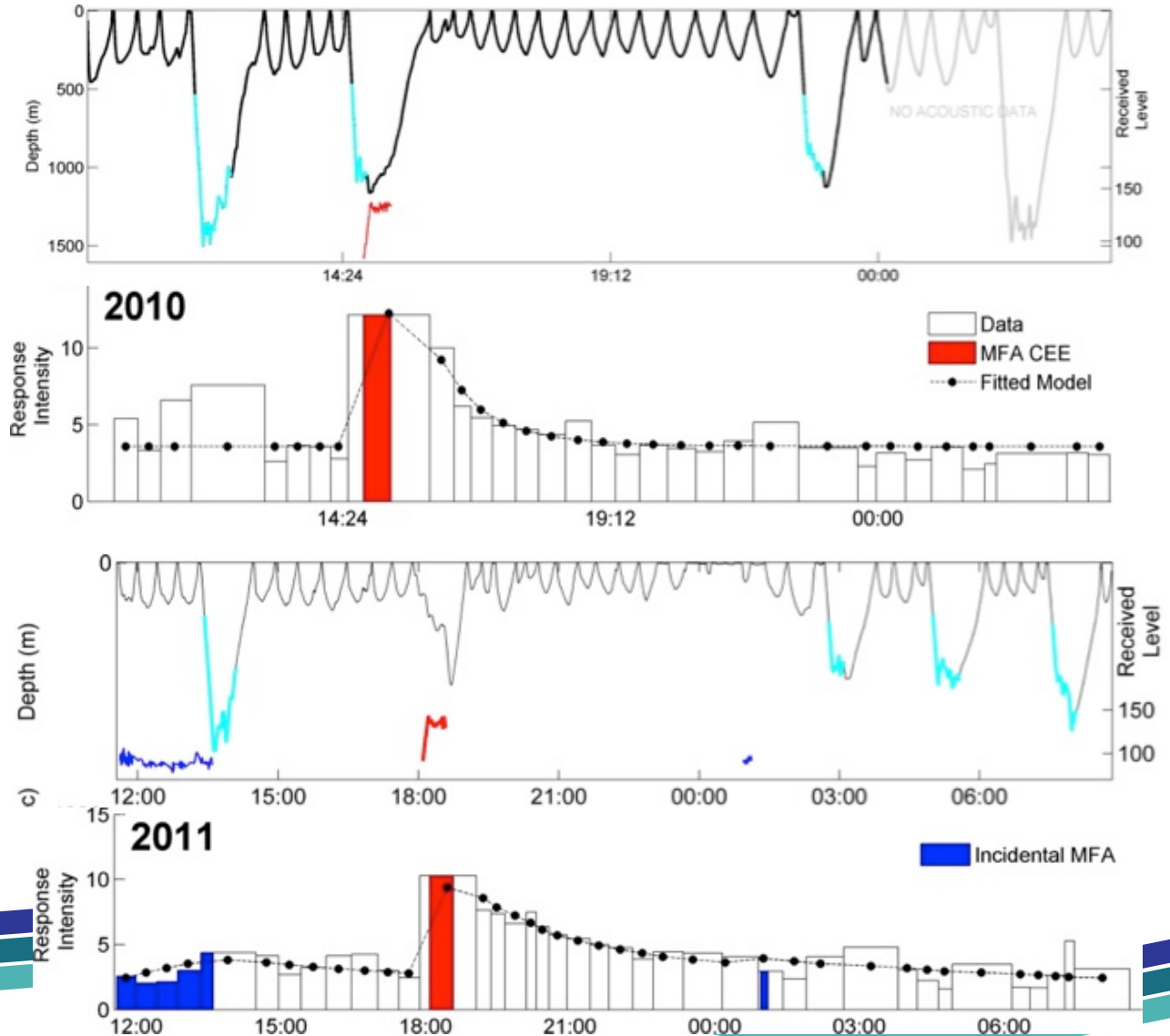
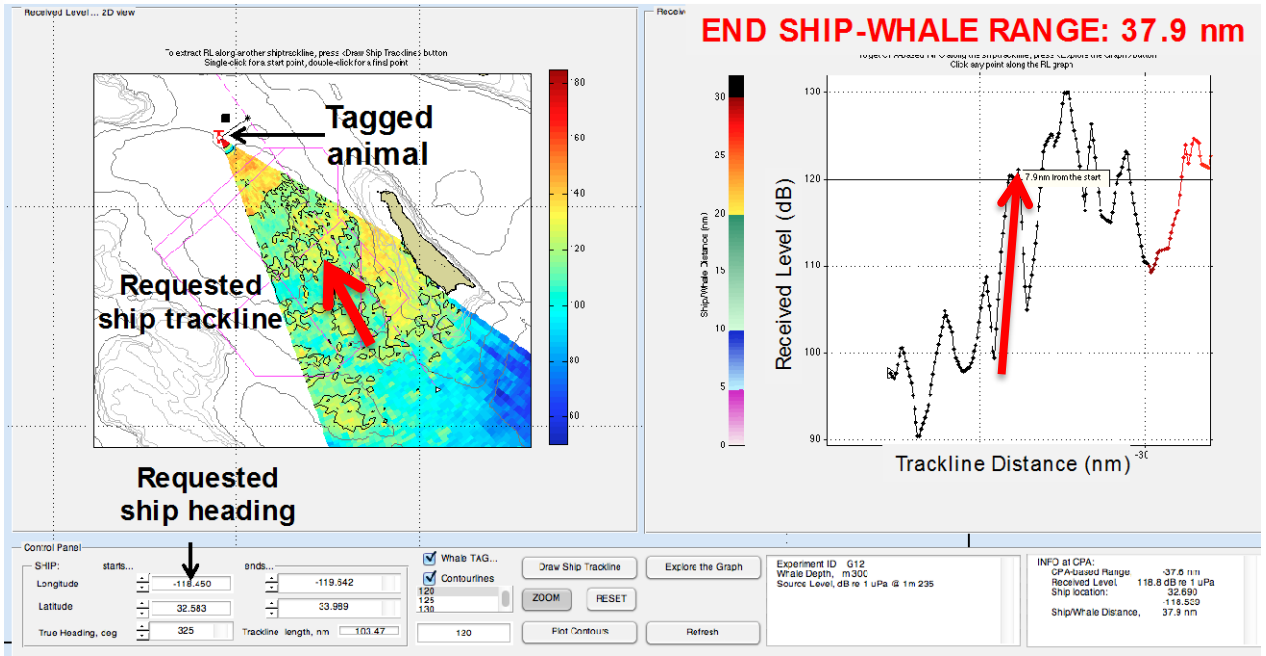
De Ruiter *et al*. (2013)

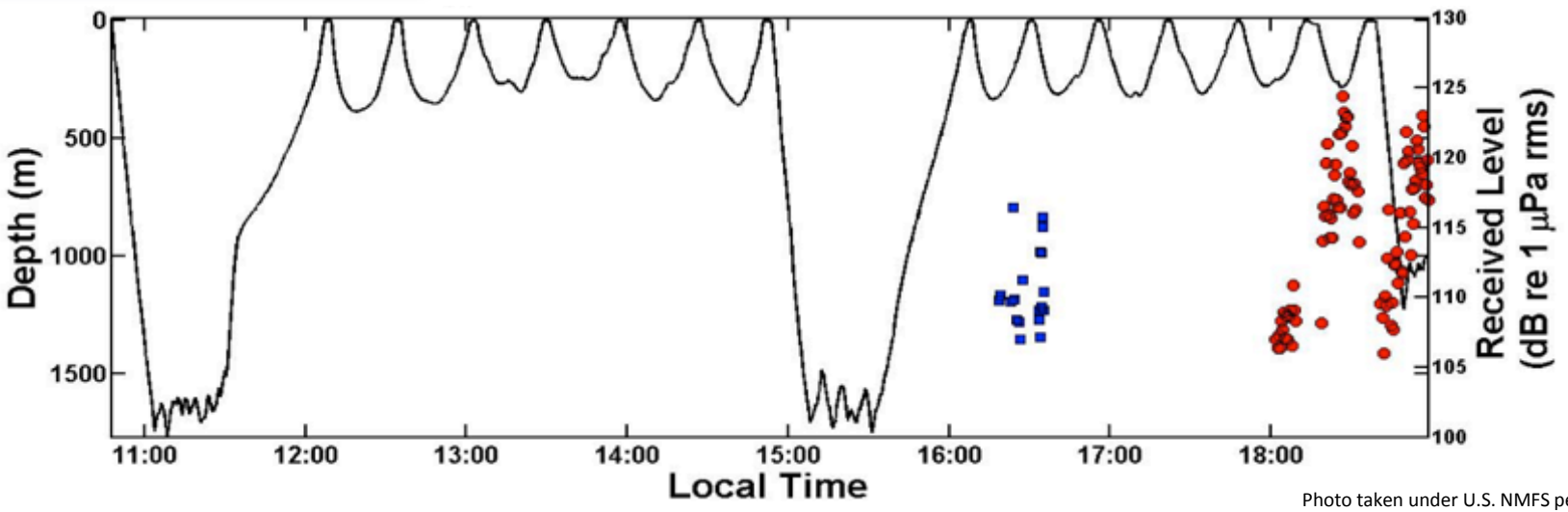


SOCAL-BRS: BEAKED WHALES (CUVIER'S REAL SHIP MFA)

livingmarine RESOURCES

SOCAL-BRS Collaboration with *USS Dewey* (DDG 105) 29 July 2013





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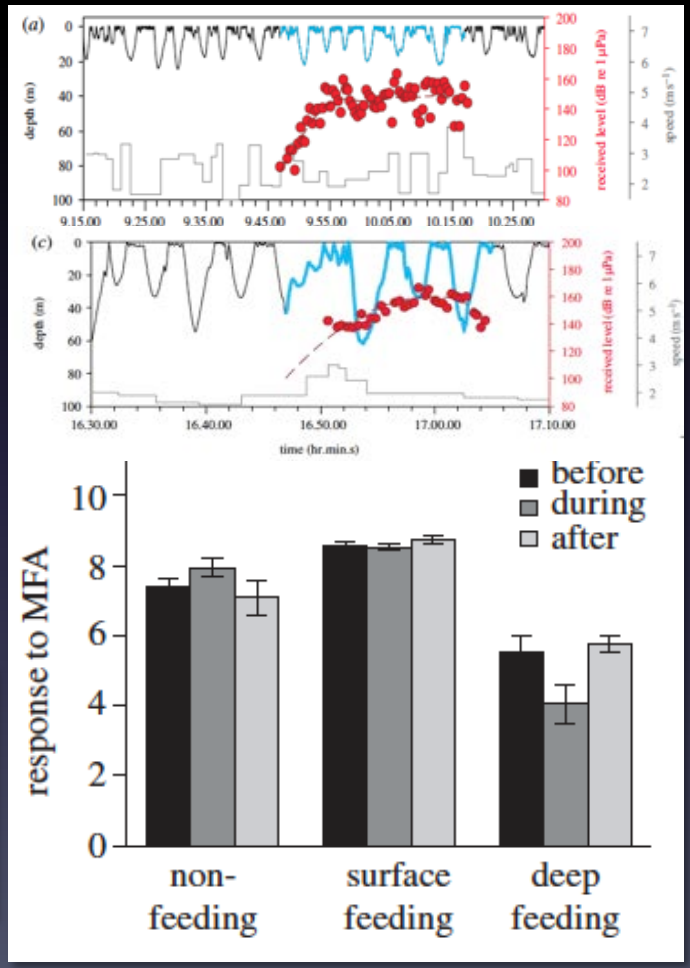
Do blue whales respond to mid-frequency sounds?

Goldbogen *et al*. (2013) used PCA/GAMM analyses to test for differences in dive behavior, kinematics, horizontal movement before, during, after CEEs *across* all individuals tested

- No clear responses in many whales
- Responses at low RLs for some
- Similar response to MFA and PRN
- Response dependent on context of exposure: ***behavioral state***



Need to understand: (1) other relevant contextual factors; (2) nature of behavioral state changes; (3) individual responses*

* Ellison et al. (2012)

Identifying Changes in Individual Behavior: *Expert Evaluation*

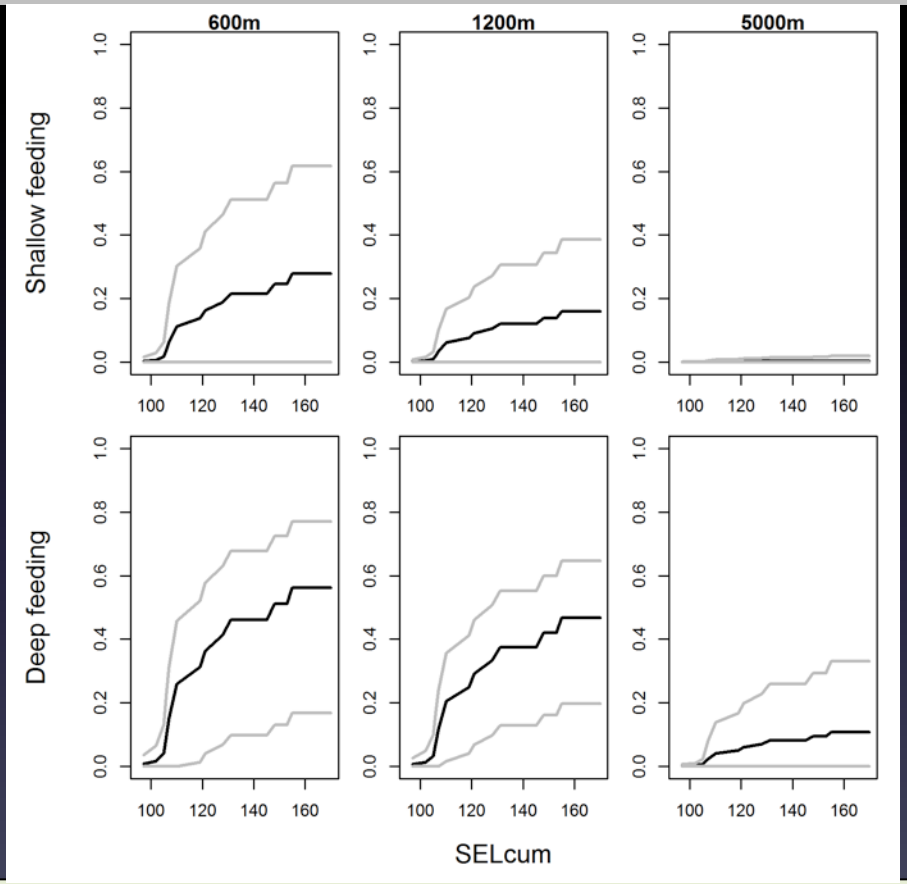
Southall *et al*. (*in prep*) used expert evaluation with response severity scoring to identify potential behavioral change-points in multivariate time-series data *within individual* CEE exposures

- Experts in two groups of three evaluate potential response relative to severity scale
  (Southall *et al*., 2007; modified by Miller *et al*., 2012)
- Experts evaluated synoptic time-series behavioral data from DTAG and focal follow:
  Depth (m) Feeding rate (lunges/dive) MSA (m/s^2)
  Heading (degrees) Horizontal Speed (m/sec) Horizontal movement (annotated map)
- Scores (and confidence level) adjudicated to a single value; higher score if multiple
- Time of response(s) identified to determine RL (max dB RMS and dB cSEL) at change point

SUMMARY OF RESPONSES (0: No response; 1: any scored response)				
SIGNAL TYPE	NON-FEEDING	DEEP FEEDING	SHALLOW FEEDING	TOTAL
MFA	1 of 2	7 of 12*	1 of 8	9 of 22
PRN	1 of 3	4 of 11	0 of 0	5 of 14
CONTROL	0 of 0	0 of 5	0 of 1	0 of 6

Blue Whale Response Probability Functions

Southall *et al*. (*in prep*) used recurrent event survival analysis to determine relationship between exposure dose (cSEL) and p(resp) for different severity levels, individual behavioral state, and source-animal range



Context (behavioral state; source range) determines p(resp) as much or more than exposure RL in blue whales

SOCAL-BRS Broad Conclusions

- Species differences (beaked whales most sensitive)
- Strong context dependence in responses

  Key factors: behavioral state, source-receiver range

- Major progress in analytical methods and multi-pronged approach for blue whales
- Major progress in using actual Navy sonar
- Expanding time/space scales of tags and CEEs

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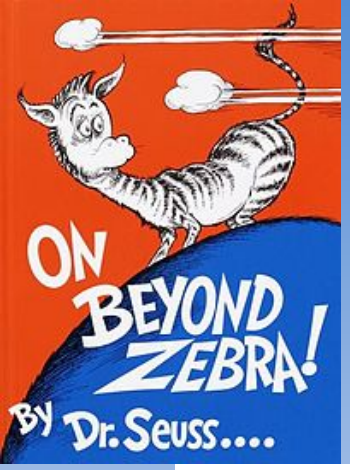
Southall et al., 2012; 2014; 2015; De Ruiter et al., 2013; Goldbogen et al, 2013; Stimpert et al., 2014; Friedlaender et al., 2016



On beyond thresholds…

Conservation Biology

Conservation Practice and Policy

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

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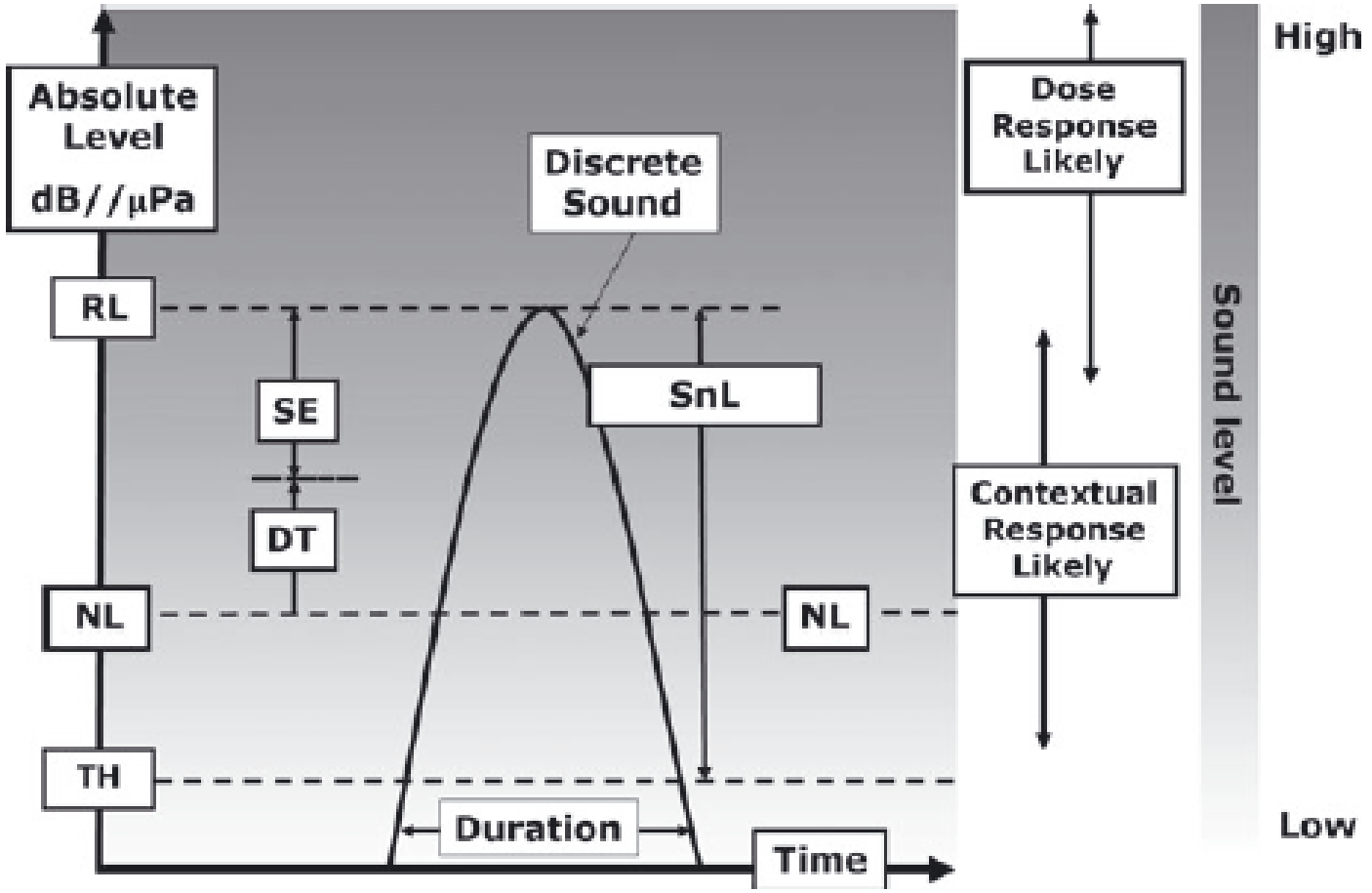

New Paradigms - Exposure Context & Broader Perspectives on Behavioral Disturbance

- 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

PARADIGM SHIFT: Concern, research, and management are broadening from severe, acute effects to non-lethal but chronic, interacting ones on realistic time/space scales