The Evolution and Application of Exposure Criteria for Assessing the Effects of anthropogenic Noise on Marine Mammals

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Biological Importance of Sound to Marine Mammals

Marine animals produce and receive sound for critical life history functions:

- **Reproduction**
- **Foraging***
- **Predator Avoidance**
- **Spatial Orientation**

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

WHEN IS NOISE A THREAT TO MARINE LIFE?

WHAT CAN BE REALISTICALLY BE DONE TO UNDERSTAND AND MITIGATE IMPACTS OF HUMAN ACTIVITIES THAT MAY BE VITAL TO ECONOMIC AND/OR NATIONAL SECURITY?

Potential Effects of Noise on Marine Mammals

- 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
- *Stranding causing injury or death*

Generally Increasing Severity

but

Generally Decreasing Occurrence

Broad Methods for Evaluating Potential Effects of Noise

- **Threshold-based methods (step-functions)**
- **Probabilistic methods (risk functions)**
- **Analytical paradigms/frameworks**
  - **Energetic and/or survival models to interpret exposures of different severity in terms of populations (PCOD)**
  - **Risk assessment methods of evaluating individual exposures given species, contextual, population and other factors**

Presentation Outline

I. Historical Perspective on Marine Mammal Noise Exposure Criteria

II. Recent/current Proposed Exposure Criteria for Auditory Effects (NOAA 2016; Southall et al., *in press*)

III. Broader Perspectives for Evaluating Consequences of Noise exposure

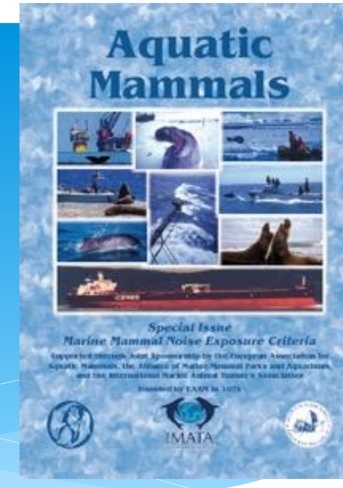
**** PCOD***

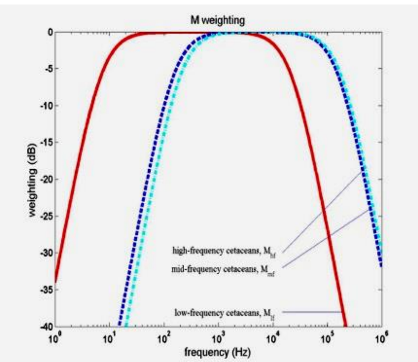
**** Biologically-Based Risk Assessment Methods***

History of NOAA Acoustic Criteria/Guidance

- **2002**: NOAA’s Ocean Acoustics Program forms marine mammal noise exposure criteria expert panel
- 2004: First “scoping meetings” - intent to develop guidance
- 2007: Southall et al (2007) published by noise exposure criteria panel; begins to be used in individual actions
- 2012: Navy (Finneran and Jenkins) report - revised weighting
- 2016: Navy (Finneran) report – significantly revised methods
- **2016**: NOAA releases acoustic technical guidance based on Finneran (2016)
- 2018: NOAA re-affirms technical guidance after executive order

Key components of Southall et al. (2007)



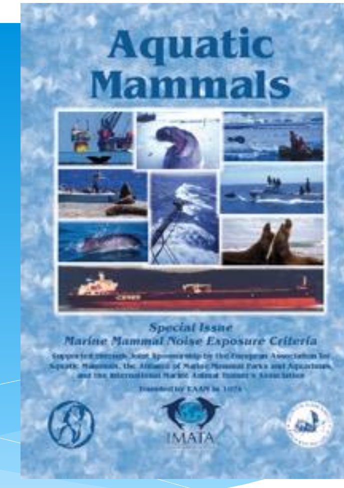


- Segregation of species into 'functional hearing groups'
- Distinction of 'pulses' and 'non-pulses'
- Creation of auditory 'M-weighting' filters
- TTS/PTS onset thresholds using dual-metric approach for both in-air and underwater exposures
- Novel behavioral response 'severity scale' and evaluation of group-specific exposure:response probability

Received Exposure Level (dB_{RMS} re: 1μPa)

Response Score	80 to <90	90 to <100	100 to <110	110 to <120	120 to <130	130 to <140	140 to <150	150 to <160	160 to <170	170 to <180	180 to <190	190 to <200
9												
8												
7										1 (6)		
6				9.5 (3,7)	47.4 (3,7)	2.2 (3,7)	1.4 (4)	2 (1,2)	5.5 (1,2,4,6)	9.3 (1,2,4,6,8)		
5					1 (3,7)		1 (4)	1 (1,2)				
4												
3									1 (1,2)	1 (1,2)		
2												
1				5 (3,7)	6 (3,7)	1 (3,7)	2 (1,2)	3 (5)				
0				59.8 (3,7)	17.7 (3,7)	1.1 (3,7,8)	0.1 (8)	0.1 (8)	6.8 (1,2,8)	6.3 (1,2,8)		

Acknowledged Limitations of Southall et al. (2007)



- Major gaps in key data areas – requisite extrapolation and precaution
- Did not include all marine mammals (U.S. and NMFS-centric)
- Conservative approach to distinction of ‘pulses’
- Did not propose explicit behavioral response threshold criteria
- Behavioral response assessment pooled different study and sound types
- Was scientifically outdated as soon as it was written

Other Relevant Developments in Marine Mammal Noise Exposure Criteria

- 2005: Verboom and Kastelein – first proposed marine mammal exposure criteria (harbor porpoise, harbor seals)
- 2013: Terhune – proposed inverse audiogram methods for harbor porpoise auditory weighting
- 2015: Tougaard et al – proposed revised exposure criteria for harbor porpoise
- Current: Revised marine mammal noise exposure criteria (update of 2007 Southall et al. criteria)

Re-Evaluating Southall et al. (2007) Noise Exposure Criteria

WHY? To evaluate progress made in measuring, modeling, and assessing the effects of noise on marine mammals and provide broadly applicable guidance to decision-makers for predicting and mitigating impacts

HOW? WHO?

- Provide updated science-based guidance on multiple parallel fronts with subject-matter experts in three key areas:
  - **Hearing, weighting functions, TTS/PTS onset**: J. Finneran, D. Ketten, P. Nachtigall, C. Reichmuth
  - **Noise exposure categorization**: W. Ellison, J. Miller, C. Greene
  - **Behavioral response**: A. Bowles, P. Tyack, L. Bejder, D. Nowacek

Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset

Challenges

- Evaluate all marine mammal species in water and (for amphibious species) in air
- Update hearing groups, weighting functions, and TTS/PTS onset criteria
- Learn from scientific and analytical progress to provide clear, fair guidance

Approach and Outcomes

(1) Segregate all marine mammals into hearing groups.

(2) Derive representative 'audiograms' for hearing groups.

(3) Derive auditory weighting and noise exposure functions using hearing and TTS data.

(4) Predict TTS and PTS onset for each hearing group

Revised noise exposure criteria:
Relationship to NOAA (2016) Acoustic Guidance

- Fundamentally based on the same quantitative process (Finneran, 2016)
- Considers all marine mammals (not NMFS- or US-centric)
- Provides aerial criteria for amphibious species (not done in NMFS, 2016)
- Systematic review of hearing, anatomical, and sound production data for all species
- Further segregations and alternate naming of hearing groups proposed
- Potential consequences of variability from median estimates considered in field application
- Our consensus results will appear in a peer-reviewed scientific journal; NMFS (2016) is a U.S.-centric policy document subject to political pressure and potential policy changes (EO #13795; NMFS, 2018).

Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset
Approach and Outcomes

(1) Segregate all marine mammals into hearing groups.

Taxon	Audiometry	Ear Type	Auditory modeling	Sound Production	Click type	References
Physeter macrocephalus Sperm whale	-	physeteroid middle ear, type I cochlea	-	SOC: 0.4 (squeal) to 9 kHz (coda) ECH: 3 to 26 kHz*	MP	Audiometry: No data Anatomical models: No data Acoustic: (Backus & Schevill, 1966; Levenson, 1974; Watkins & Schevill, 1977, 1980; Watkins, 1980; Weilgart & Whitehead, 1988; Goold & Jones, 1995; Madsen, Wahlberg, et al., 2002, Madsen, Payne, et al., 2002; Møhl et al., 2003; Weir et al., 2007)
Ziphius cavirostris Cuvier's beaked whale goose-beaked whale	-	physeteroid middle ear	-	ECH: 28 to 47 kHz*	FM	Audiometry: No data Anatomical models: No data Acoustic: (Frantzis et al., 2002; Zimmer et al., 2005; Baumann-Pickering, McDonald, et al., 2013)
Delphinapterus leucas Beluga	BEH: 0.04 to 130 kHz AEP: < 4 to 150 kHz	odontocete middle ear	-	SOC: 0.1 (whistle, pulsed calls) to 21 kHz (whistle, pulsed calls) ECH: 40 to 120 kHz* click type: BBHF	BBHF	Audiometry: BEH: (White et al., 1978; Awbrey, 1988; Johnson et al., 1989; Ridgway et al., 2001; Finneran, Carder, Dear, et al., 2005, Finneran et al.)(n=8); exclude (Finneran et al., 2005, individual "*Turner*"); AEP: (Popov & Supin, 1990; Klishin et al., 2000; Mooney et al., 2008; Popov et al., 2013; Castellote et al., 2014)(n=12) Anatomical models: No data Acoustic: (Kamminga & Wiersma, 1981; Sjare & Smith, 1986; Au et al., 1987; Turl et al., 1991; Belikov & Bel'kovich, 2001, 2005, 2006, 2007; Karlsen et al., 2001; Rutenko & Vishnyakov, 2006; Lammers & Castellote, 2009; Chmelnitsky & Ferguson, 2012)

Revised noise exposure criteria:

Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(1) Segregate all marine mammals into hearing groups.

Marine Mammal Hearing Group	Auditory Weighting Function	Genera (or species) Included	Group-Specific Appendix
Very Low-Frequency & Low-Frequency Cetaceans	LF	***Balaenidae*** *(Eubalaenidae spp.; Balaena mysticetus;)* ***Balaenopteridae*** *(Balaenoptera musculus, B. physalus)*	1
		Balaenopteridae *(Balaenoptera acutorostrata, B. bonaerensis, B. omurai, B. edeni, B. borealis; Megaptera novaeangliae);* ***Neobalenidae*** *(Caperea);* ***Eschrichtiidae*** *(Eschrichtius)*	
Mid-Frequency & High-Frequency Cetaceans	HF	***Physeteridae*** *(Physeter);* ***Ziphiidae*** *(Berardius spp., Hyperoodon spp., Indopacetus, Mesoplodon spp., Tasmacetus, Ziphius);* ***Delphinidae*** *(Orcinus)*	2
		Delphinidae *(Steno, Sousa spp., Sotalia spp., Tursiops spp., Stenella spp., Delphinus, Lagenodelphis, Lissodelphis spp., Grampus, Peponocephala, Feresa, Pseudorca, Globicephala spp., Orcaella spp., Lagenorhynchus acutus, L. albirostris, L. obliquidens, L. obscurus);* ***Montodontidae*** *(Delphinapterus, Monodon);* ***Plantanistidae*** *(Plantanista)*	
Very High-Frequency Cetaceans	VHF	***Phocoenidae*** *(Phocoena spp., Neophocaena spp., Phocoenoides);* ***Iniidae*** *(Inia);* ***Kogiidae*** *(Kogia);* ***Lipotidae*** *(Lipotes);* ***Pontoporiidae*** *(Pontoporia);* ***Delphinidae*** *(Cephalorhynchus spp.; Lagenorhynchus cruciger, L. austrailis)*	3
Sirenians (**SI**)	SI	***Trichechidae*** *(Trichechus spp.);* ***Dugongidae*** *(Dugong)*	4
Phocid Carnivores in Water (**PCW**) Phocid Carnivores in Air (**PCA**)	PCW PCA	***Phocidae*** *(Cystophora, Erignathus, Halichoerus, Histriophoca, Hydrurga, Leptonychotes, Lobodon, Mirounga spp., Monachus, Neomonachus, Ommatophoca, Pagophilus, Phoca spp., Pusa spp.)*	5
Other Marine Carnivores in Water (**OCW**) Other Marine Carnivores in Air (**OCA**)	OCW OCA	***Odobenidae*** *(Odobenus);* ***Otariidae*** *(Arctocephalus spp., Callorhinus, Eumetopias, Neophoca, Otaria, Phocarctos, Zalophus spp.);* ***Ursidae*** *(Ursus maritimus);* ***Mustelidae*** *(Enhydra, Lontra feline)*	6

Revised noise exposure criteria:

Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(2) Derive representative ‘audiograms’ for hearing groups.

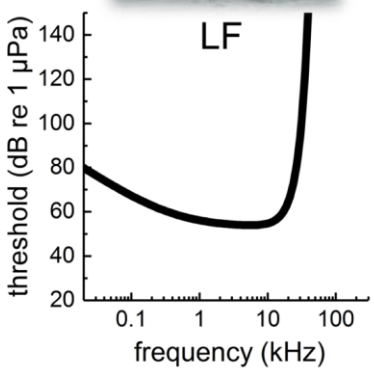
Estimated group ‘audiograms’ based on median threshold value at each frequency among all individuals of any species within a group where behavioral hearing data were available; function determined with equation derived from Popov et al. (2007) by Finneran (2016):

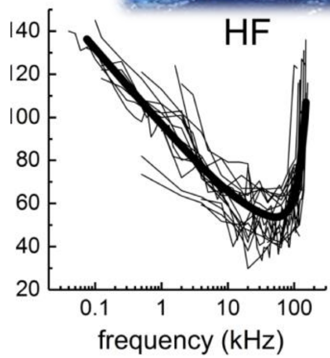
$$T(f) = T_0 + A\log_{10}\left(1 + \frac{F_1}{f}\right) + \left(\frac{f}{F_2}\right)^B$$

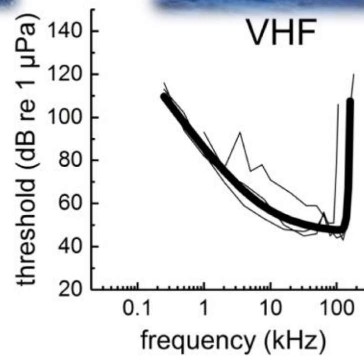
- T_0 fits the overall vertical position of the curve such that the lowest value occurs at the frequency at which the lowest threshold was measured;
- F_1 is the inflection point of the low-frequency rolloff;
- A is a fitting parameter related to the slope of the low-frequency rolloff;
- F_2 is the inflection point and slope of the high-frequency rolloff; and
- B is a fitting parameter related to the slope of the high-frequency rolloff.

Separate estimation process applied for mysticetes given absence of direct measurements of hearing

Estimated hearing curves for marine mammal groups







Cetaceans:

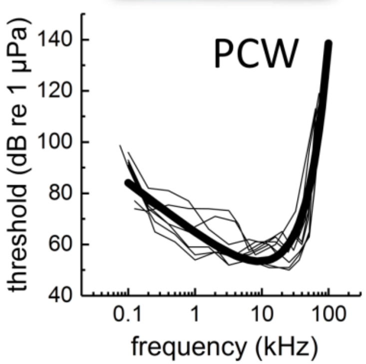
Very Low (VLF) (no function)

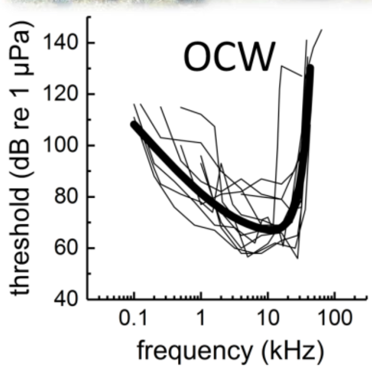
Low Frequency (LF) (estimated)

Mid Frequency (MF) (no function)

High Frequency (HF)

Very High Frequency (VHF)

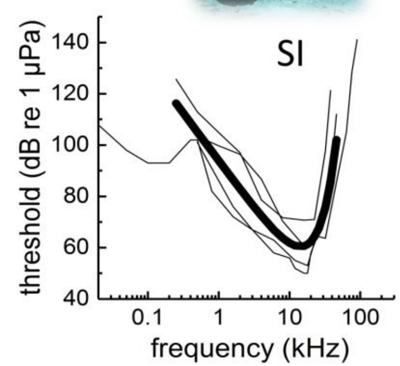




Marine Carnivores:

Phocid Carnivores in Water (PCW)*

Other Marine Carnivores in Water (OCW)*



Sirenians (SI)

Southall et al (*in press*) – derived from Finneran (2016)

*** Aerial audiograms (PCA & OCA)**

Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(3) Derive auditory weighting and noise exposure functions hearing and TTS data.

Auditory ***weighting functions*** describe relative sensitivity within the audible range – derived with a generic band-pass filter equation:

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\}$$

C defines the vertical position of the curve and is selected such that the maximum amplitude of the function = 0 dB

Auditory ***exposure functions*** combine weighting function with the weighted threshold to predict TTS or PTS onset thresholds as a function of noise frequency

$$E(f) = K - 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\}$$

K determines the vertical position of the curve and is defined so that the minimum amplitude of the function equals the weighted TTS or PTS threshold

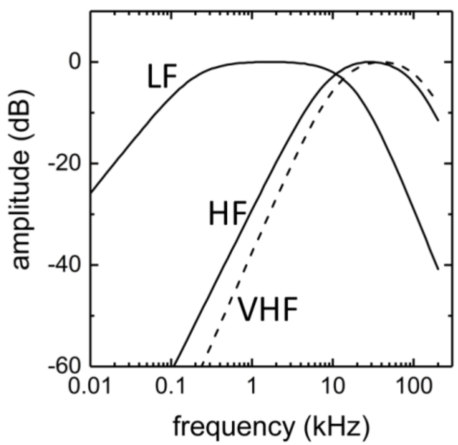
- f_1 is the inflection point of the low-frequency rolloff;
- a is a fitting parameter related to the slope of the low-frequency rolloff;
- f_2 is the inflection point of the high-frequency rolloff; and
- b is a fitting parameter related to the slope of the high-frequency rolloff.

Revised noise exposure criteria:

Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(3) Auditory weighting functions



Cetaceans:

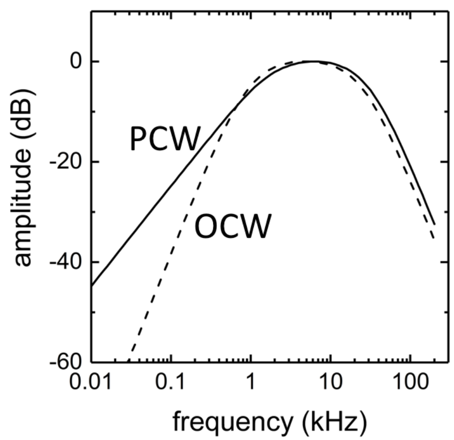
Very Low (VLF) (no function)

Low Frequency (LF) (estimated)

Mid Frequency (MF) (no function)

High Frequency (HF)

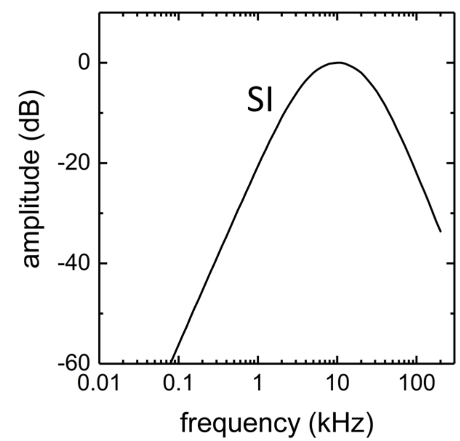
Very High Frequency (VHF)



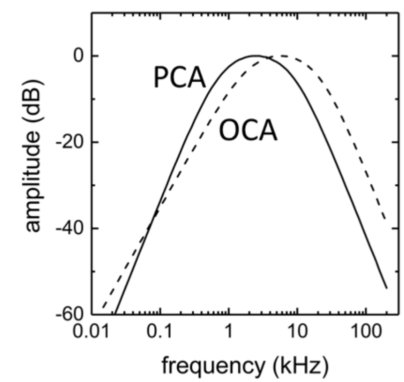
Marine Carnivores:

Phocid Carnivores in Water (PCW)

Other Marine Carnivores in Water (OCW)



Sirenians (SI)

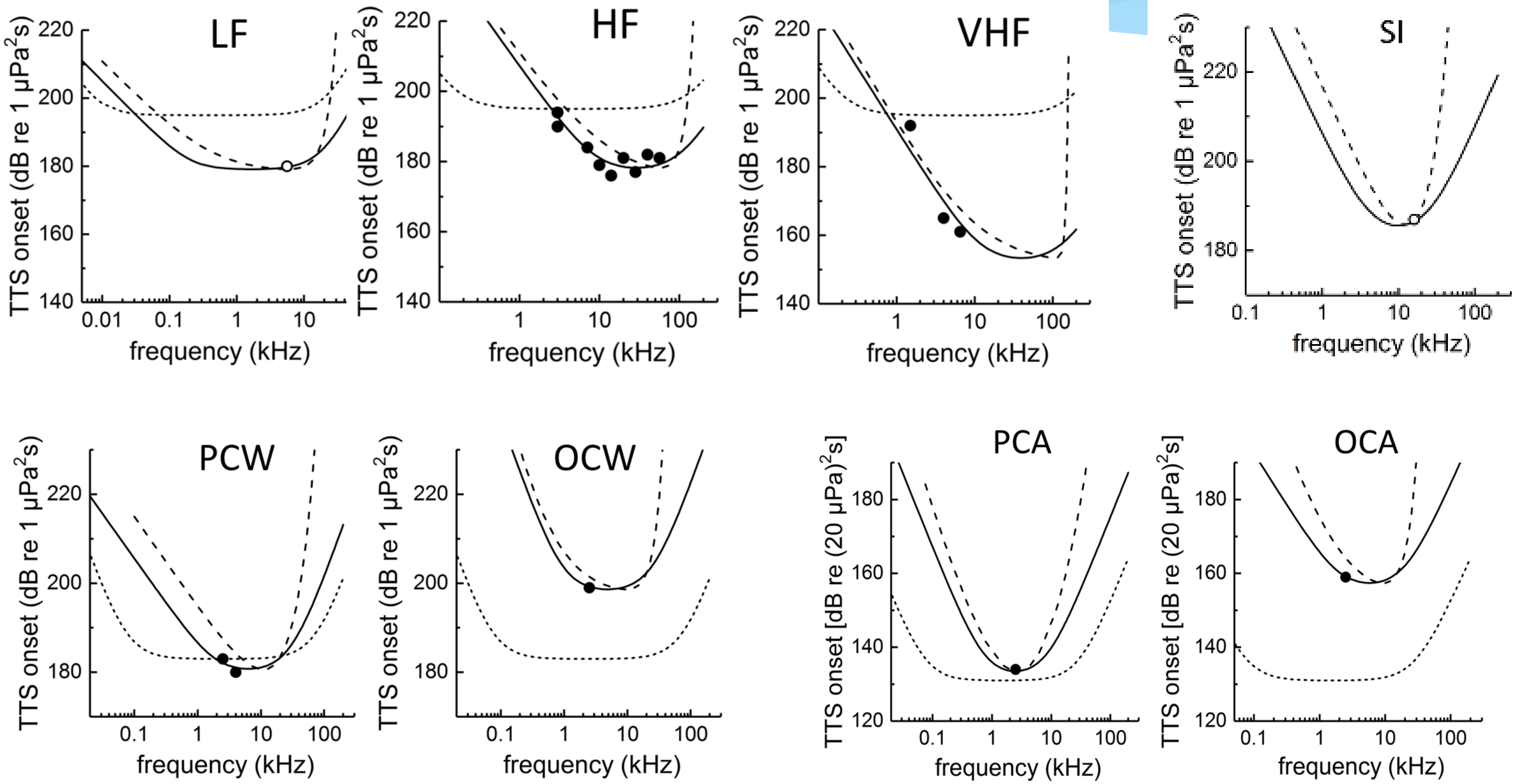


Southall et al (*in press*) – derived from Finneran (2016)

Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(3) Auditory exposure functions



Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset

Approach and Outcomes

(4) Predict TTS and PTS onset for each hearing group

- *TTS onset using either exposure functions (shape assumed same for non-impulsive and impulsive noise; different onset) or extrapolation methods*
- *PTS onset using estimates of TTS growth rates.*

Most extrapolation procedures for TTS onset (groups with no data) and TTS growth rates based on Southall et al. (2007) with slight modifications by Finneran et al. (2016)

TTS & PTS onset: Non-impulsive Exposures

Marine Mammal Hearing Group	TTS-onset: SEL (weighted)	PTS-onset: SEL (weighted)
LF	179	199
HF	178	198
VHF	153	173
SI	186	206
PCW	181	201
OCW	199	219
PCA	134	154
OCA	157	177

TTS & PTS onset: Impulsive Exposures

Marine Mammal Hearing Group	TTS-onset: SEL (weighted)	TTS-onset: peak SPL (unweighted)	PTS-onset: SEL (weighted)	PTS onset: peak SPL (unweighted)
LF	168	213	183	219
HF	170	224	185	230
VHF	140	196	155	202
SI	175	220	190	226
PCW	170	212	185	218
OCW	188	226	203	232
PCA	123	138	138	144
OCA	146	161	161	167

Revised noise exposure criteria:
Noise Type Categorization

Challenges

- Develop quantitative methods to appropriately characterizing impulsive signals accounting for well-known propagation effects
- Propose a measurement-based, implementable, and reasonably precautionary procedure, given major limitations in hearing data regarding potential metrics and thresholds

Approach and Outcomes

(1) Characterize temporal-spectral-spatial factors and reaffirm impulsive/non-impulsive source types

(2) Consider metrics for impulsive-non-impulsive distinction (*e.g.*, kurtosis, P-P, crest factor, rise time)

(3) In absence of auditory data to evaluate 'thresholds' for any of these metrics, propose a relatively simple proxy that is generally correlated with most aspects of 'sharpness' - high frequency signal content

Revised noise exposure criteria:
Behavioral Response Severity Evaluation

Challenges

- Revisit behavioral response severity assessment
- Consider segregation of discrete exposure events and broader scale disturbance
- Consider broader suite of exposure, contextual, and response variables
- Evaluate revised severity assessment processes for selected examples

Approach and Outcomes

(1) New methods developed to evaluate disturbance on broader temporal-spatial scales where individual/group exposure unknown

(2) Substantially revised behavioral response severity scales for:

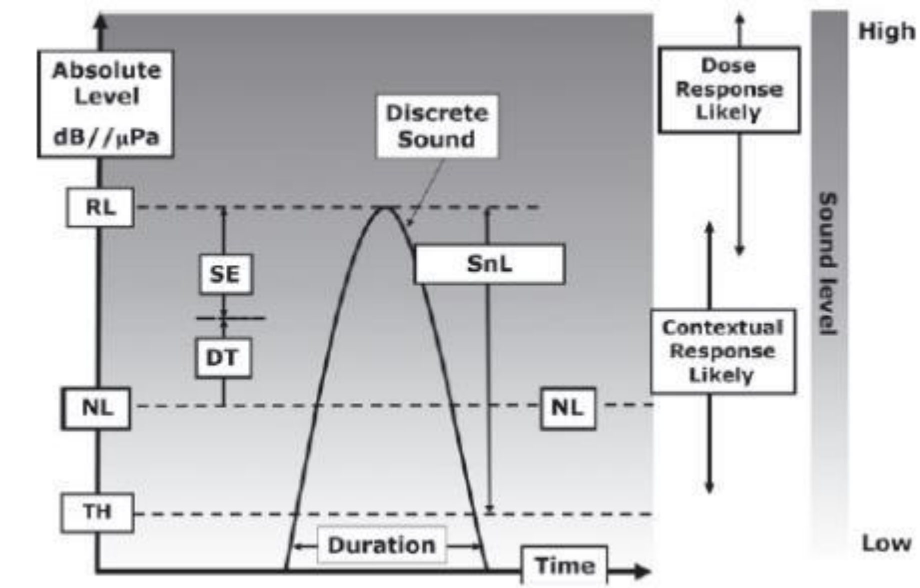
- Free-ranging animals: vital rate perspective (survival, foraging, reproduction)
- Captive subjects: changes in untrained and trained behaviors

Conservation Biology

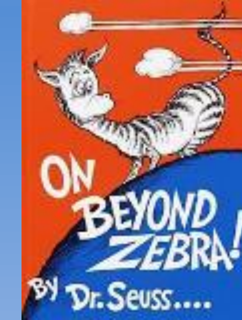
Conservation Practice and Policy

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

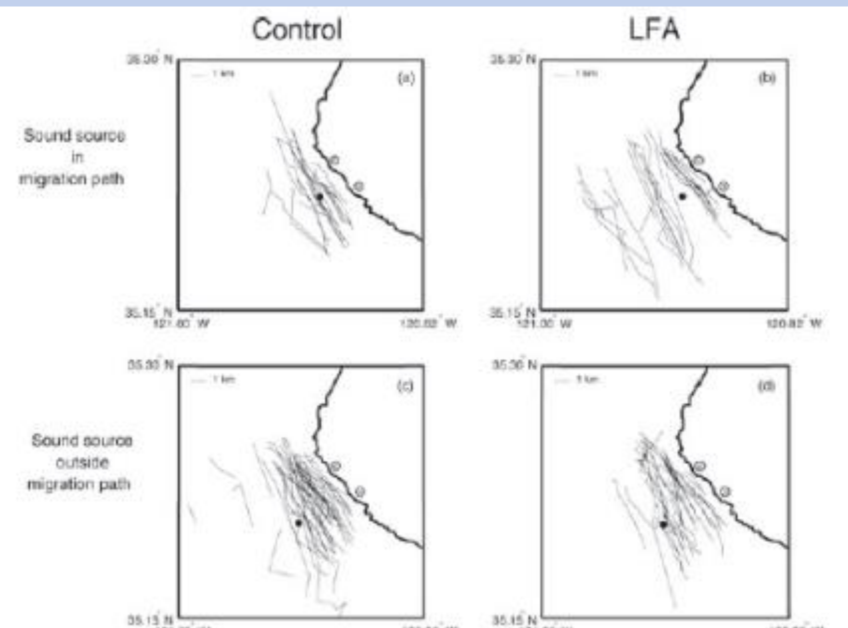
W.T. ELLISON,* B.L. SOUTHALL,†‡ C.W. CLARK,§ AND A.S. FRANKEL*



On beyond thresholds…

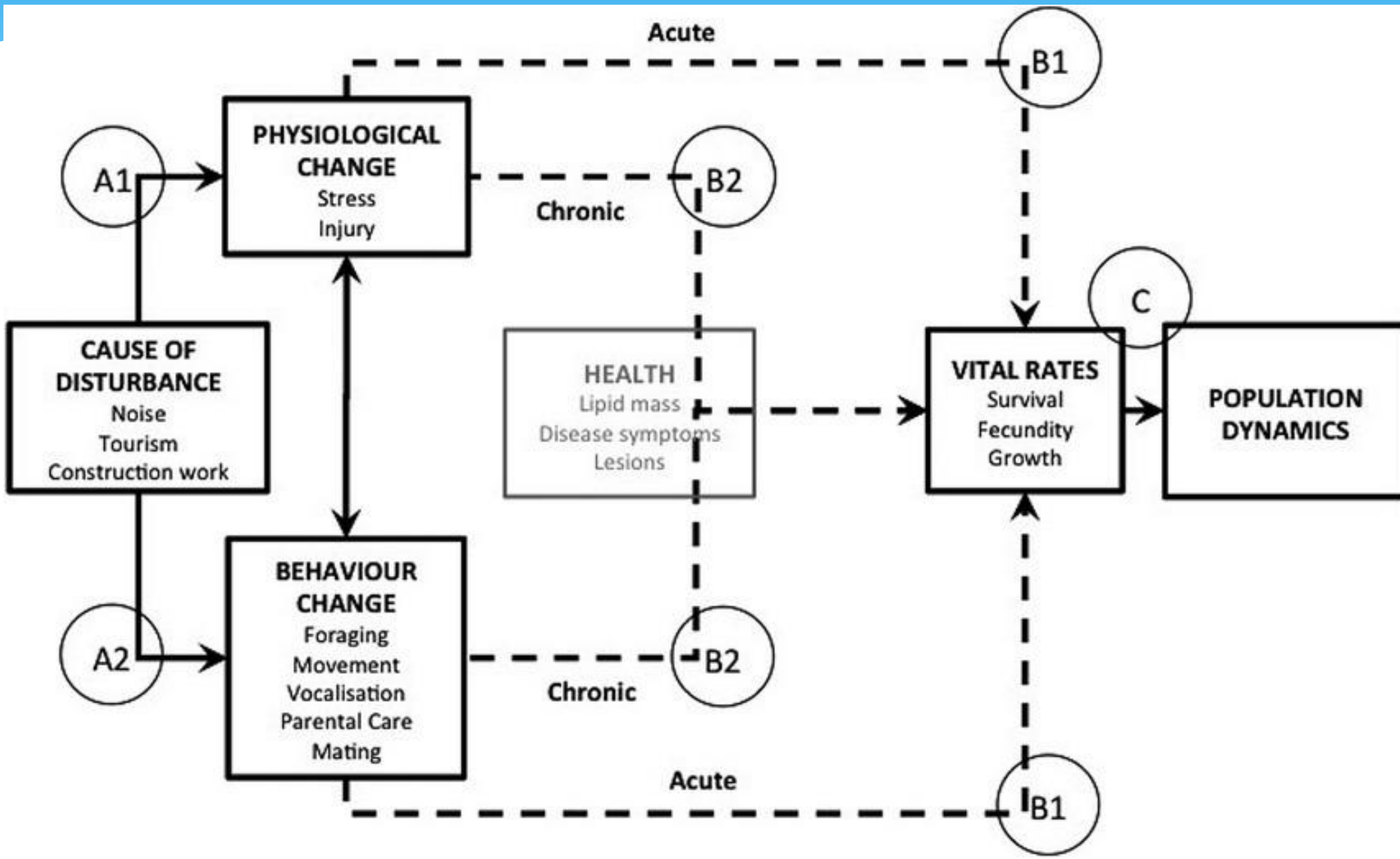


Contextual Factors Influencing Response Probability: Spatial Orientation



Courtesy: J. Buck, P. Tyack

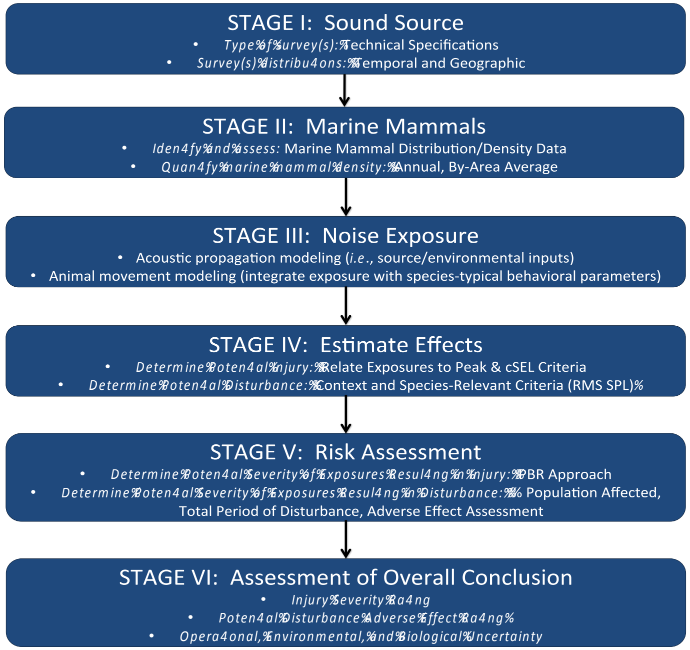
Going to Scale:
Population Consequences of Disturbance



King et al (2015)
Pirotta et al. (2018)

Risk Assessment Framework: Biological Significance of Noise Exposure

- Wood et al (2012) developed risk assessment methods using probabilistic functions for disturbance for PG&E seismic survey
- Ellison et al. (2016) adapted approach into an explicit framework for Acute Noise Exposure Events
  - Injury evaluated as PTS exposures interpreted in PBR context
  - Behavioral Disturbance evaluated as probability response for individuals in population as a function of time (PCOD) relative to species-specific vulnerability (life history traits, environmental/contextual factors)



Risk Assessment Framework: Biological Significance of Noise Exposure (Southall et al., 2018; *in prep*)

A Risk Assessment Framework to Evaluate the Potential Relative Effects of Noise on Marine Mammals

Southall, B.L.[1,2], Amaral, J.[3], Clark, C.W.[3,5], Ellison, W.[3], Joy, R.[4] and Tollit, D.[4], Ponirakis, D.W.[5]
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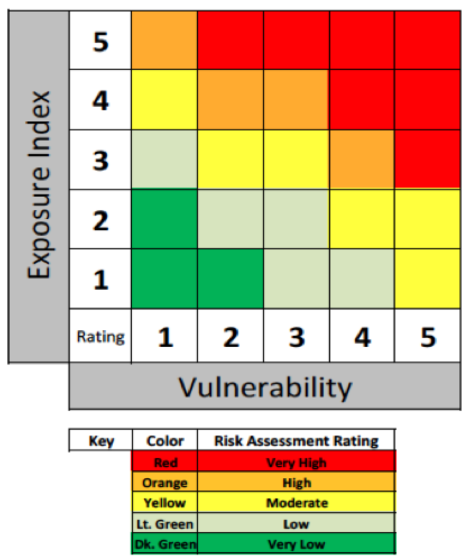
Aggregate Exposure Risk Assessment

Species-Specific Exposure Magnitude ("Exposure Index")

A modular, quantitative process is applied to calculate an "Exposure Index" relating known (or predicted) human activities as distributed sources of disturbance for marine mammals within broadly defined areas based on species-specific distribution patterns.

* Quantitative basis is spatial, temporal, and spectral overlap between activities and species



Species-Specific Vulnerability

(*Applied in both acute and aggregate approaches*)

- Species-specific vulnerability rating is determined using a structured evaluation of key species and environmental context-specific factors.
- The factors used to determine an overall potential vulnerability rating include:

1. ***Species Population***
2. ***Species Habitat Use and Compensatory Abilities***
3. ***Potential Masking***
4. ***Other Environmental Stressors***

SUMMARY - DISCUSSION

- Substantial scientific progress has been made in understanding the effects of noise on marine mammals
- Modified exposure criteria are more empirically informed, although major data gaps remain
- Exposure criteria are just part of an informed process
  - Should be adaptive and responsive to reality checks from observations
  - Step functions are limited - nature is probabilistic
  - Broader analytical frameworks are required (PCOD, risk assessment)
- Applications and mitigation of disturbance should be strategic to avoid injury and population-level effects; must account for the full scope of environmental 'value' of activities.

RESERVE SLIDES

A Risk Assessment Framework to Evaluate the Potential Relative Effects of Noise on Marine Mammals

Southall, B.L.1,2, Amaral, J.3, Clark, C.W.3,5, Ellison, W.3, Joy, R.4 and Tollit, D.4, Ponirakis, D.W.5

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3 Marine Acoustics, Inc. , 4 SMRU Consulting, 5 Cornell Bioacoustics Research Program

Background

Following earlier efforts to apply risk assessment methods in evaluating the effects of noise on marine mammals within environmental impact assessment projects (Wood et al., 2010), several of the authors here began to adapt and derive such methods to evaluate potential effects of discrete acoustic exposure events. The initial objective of an Expert Working Group (EWG) was to develop a transparent and structured process that included logical elements of previous assessment methods for estimating potential effects of noise on hearing and behavior, and also integrated relevant biological, acoustical, ecological, and environmental contextual variables within a population context. The resulting risk assessment framework (Ellison et al., 2015) was influenced by a number of important emergent conclusions from the past several decades of science on these issues (*e.g.*, Clark et al., 2009; Ellison et al., 2012; 2018; Southall et al., 2017). These include the following observations:

- Industrial activities occur within complex acoustic environments involving other human and natural sound sources and consequently, aspects of noise exposure beyond simply received sound level should be considered.
- The geographic scales for noise impact assessments should be broader than previously considered.
- Potential effects are critically dependent on the spatial, temporal, spectral, and contextual nature of the noise in relation to hearing and the spatio-temporal distribution of species in question.
- Potential effects should be evaluated within a biological-ecological significance framework that incorporates key species-specific parameters such as population status, distribution patterns, adaptability, and variability and uncertainty in these and other parameters.

Objectives and Approaches

The EWG's initial objective was to develop a biologically-based and scientifically-current process with logical elements from previous assessment methods for evaluating effects on hearing and behavior, and to integrate relevant biological, acoustical, ecological, and environmental contextual variables in evaluating significance of noise exposure within a population context. The first approach (***acute exposure risk assessment***) was designed to evaluate acute events (e.g., seismic surveys, discrete pile-driving operations) and was deliberately designed to ensure consistency with current U.S. regulatory assessments by adapting aspects of existing analytical methods (Ellison et al., 2015). The initial risk assessment framework evaluated the relative magnitude and duration of exposure in terms of its potential *severity* within a population perspective using population consequences of disturbance (PCOD) methods. This evaluated risk was then considered for certain (behavioral) impacts in relation to a host of life history, population, contextual, and environmental parameters considered to mediate the potential species-specific *vulnerability* to disturbance.

The ongoing EWG effort described here aims to improve and adapt the original risk assessment framework for two very different levels of evaluation. The ***acute exposure risk assessment*** approach retains the perspective of a discrete, identifiable acoustic activity within the context of injury and behavioral response. The second approach (***aggregate exposure risk assessment)*** moves to broader temporal and spatial scales and considers the potential risk of many overlapping activities within an aggregate framework and without reference to specific effects (but rather a relative disturbance index). Both approaches share some common philosophies in terms of evaluating overall exposure magnitude and comparing this with species-specific biological and environmental variables in estimating vulnerability. However, there are also fundamental differences, including how the magnitude of exposure is quantified and how potential susceptibility to masking is quantified. Both the acute and aggregate risk assessment frameworks are presented as overviews. It should be clearly recognized that this project is in progress and is expected to appear subsequently in further developed and published format.

Acute Exposure Risk Framework – Overall Design

Acute Exposure Risk Assessment (Potential Injury)

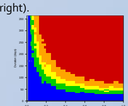
- Estimates of total number of individuals predicted to experience physical injury (defined as PTS onset), given specified noise exposure criteria thresholds are determined.
- The total number is related to the residual potential biological removal (PBR), and a relative risk assessment rating is determined.

Description	Rating	Severity rating threshold definition
Very High	5	>200% of stock population residual PBR affected
High	4	101%- 200% of stock population residual PBR affected
Moderate	3	51%-100% of stock population residual PBR affected
Low	2	11%-50% of stock population residual PBR affected
Very Low	1	<10% of stock population residual PBR affected

Acute Exposure Risk Assessment – Behavioral Response Severity

- Risk scores, relating the relative magnitude (M; defined as the proportion of the total zone population estimated to be disturbed) and duration (D) of exposure, based on median paired undisturbed and disturbed population differences as a percentage of potential biological removal (PBR), are calculated and color coded (explanation below left).
- This risk score is the Y-axis (severity) of a M-D behavioral risk assessment matrix (example, below right).

Color Code (risk category score)	Explanation
Red (5)	M-D scenarios in which median disturbed population decline > 200% of PBR (proportion > 2.0)
Orange (4)	M-D scenarios in which median disturbed population decline > 100% but ≤ 200% of PBR (proportion > 1.0 but ≤ 2.0)
Yellow (3)	M-D scenarios in which median disturbed population decline between 50% but ≤100% of PBR (proportion > 0.5 but ≤ 1.0)
Green (2)	M-D scenarios in which median disturbed population decline between > 10% but ≤ 50% of PBR (proportion > 0.1 but ≤ 0.5)
Blue (1)	M-D scenarios in which median disturbed population decline ≤ 10% of PBR (proportion ≤ 0.1)



EXAMPLE: M-D risk matrix for large zone population (n=63,492) of Bottlenose dolphin based on median population difference between paired undisturbed and disturbed populations following 500 Interim PCoD simulations.

Species-Specific Vulnerability

(Applied in both acute and aggregate approaches)

- Species-specific vulnerability rating is determined using a structured evaluation of key species and environmental context-specific factors.
- The factors used to determine an overall potential vulnerability rating include:

1. Species Population

2. Species Habitat Use and Compensatory Abilities

3. Potential Masking

4. Other Environmental Stressors

Vulnerability Factor 1. Species Population Factor (defined for area-specific stock)	Score (max 7)
Population Status: Endangered (ESA) or depleted (MMPA), or	+3
Population Status: Threatened	+1
Population Trend: Decreasing (last three stock assessment reports (SARs) for which new population estimates were updated), or	+2
Population Trend: Unknown (last three SARs) or data deficient	+1
Population Trend: Stable (last three stock assessment reports (SARs) for which new population estimates were updated within 5%), or	0
Population Trend: Increasing (last three SARs), or	-1
Population Size: Small (n <2500, as specified by IUCN designation)	+2

Vulnerability Factor 2. Species Habitat and Temporal Factors	Score (max 7)
Habitat Use: Specified area contains ≥30% of total region-wide, or estimated population (during defined survey period), or	+4
Habitat Use: Specified area contains <30% and ≥15% of region-wide population, or	+2
Habitat Use: Specified area contains <15% and ≥5% of region-wide population, or	+1
Habitat Use: Specified area contains <5% of region-wide population	0
Temporal overlap: High probability that activity will overlap with concentrated breeding/maternal care periods and/or key feeding or migration periods within specified area, or	+3
Temporal overlap: Moderate probability that activity will overlap with concentrated breeding/maternal care periods and/or key feeding or migration periods within specified area, or	+2
Temporal overlap: Some (low) probability that activity will overlap with concentrated breeding/maternal care periods and/or key feeding or migration periods within specified area. This score also assigned when insufficient data on species biology exists by which to assess potential overlap.	+1

For the acute exposure risk assessment, a qualitative evaluation of masking potential is applied to evaluate potential masking of signals associated with communication, foraging, and navigation/orientation.

Vulnerability Rating 3 (Acute). Activity Specific Auditory Masking Factor	Score (max 9)
Communication Masking: Predominant noise energy directly overlaps species-specific signals utilized for communication.	+4
Communication Masking: Predominant noise energy partially overlaps species-specific signals utilized for communication.	+1
Foraging Masking: Predominant noise energy directly overlaps species-specific signals utilized in foraging (including echolocation and other foraging coordination signals).	+3
Foraging Masking: Predominant noise energy partially overlaps species-specific signals utilized in foraging.	+1
Navigation/Orientation Signal Masking: Predominant noise energy directly overlaps signals likely utilized in spatial orientation to which species is well capable of hearing	+2
Navigation/Orientation Signal Masking: Predominant noise energy partially overlaps signals likely utilized in spatial orientation to which species is somewhat capable of hearing	+1

For the aggregate noise risk assessment, an alternative method is used for calculating the masking factor score. It includes the following steps:

- Generate an M-weighted, aggregate noise spectrum for a defined area and period.
- Estimate relative spectrum level differences between the M-weighted, aggregate noise spectrum and baseline ambient noise.
- Convert these ambient noise-to-noise spectrum differences into ambient noise-to-noise level ratios (ANNR) for each of three context-specific frequency bands representing masking under LF, MF and HF biological contexts.

Vulnerability Factor 3 (Aggregate). Potential Masking Factor	Score (max 9)
Communication Masking Factor: Median ANNR (for all cells within zone in which species is predicted to occur) within primary species-specific communication (conspecific and auto-communication) band is > 30 dB	+6
Communication Masking Factor: Median ANNR within primary species-specific communication (conspecific and auto-communication) band is 10-30 dB	+3
Communication Masking Factor: Median ANNR within primary species-specific communication (conspecific and auto-communication) band is 1-10 dB	+1
Communication Masking Factor: Median ANNR within primary species-specific communication (conspecific and auto-communication) band is <1 dB	0
Spatial Orientation and Navigation Masking Factor: Median ANNR within LF band is > 30 dB	+2
Spatial Orientation and Navigation Masking Factor: Median ANNR within LF band is 10-30 dB	+1
Spatial Orientation and Navigation Masking Factor: Median ANNR within MF band is >30 dB	+1

Vulnerability Factor 4. Other Stressors	Score (max 7)
Chronic anthropogenic noise: Species subject to variable levels of current or known future chronic anthropogenic noise (i.e., dense or overlapping concentrations of industrial activity (e.g., shipping lanes, sonar testing ranges, areas of regular seismic surveys)), or	Up to 2
Chronic anthropogenic risk factors (non-noise): Species subject to variable degrees of current or known future risk from other chronic, non-noise anthropogenic activities (*e.g.*, regular documented cases of fisheries interactions, ship-strike; last SARs to serve as reference), or	Up to 3
Chronic biological risk factors (non-noise): Variable presence of disease, parasites, prey limitation, or high predation pressure (last SARs to serve as reference).	Up to 2

Aggregate Exposure Risk Assessment

Species-Specific Exposure Magnitude ("Exposure Index")

A modular, quantitative process is applied to calculate an "Exposure Index" relating known (or predicted) human activities as distributed sources of disturbance for marine mammals within broadly defined areas (i.e zones) based on species-specific distribution patterns.

First, an "Activity Index" is calculated for each zone within a larger region and is based on date, duration and area covered by each activity in the zone The Activity Index is a function of aggregate spatial an temporal "risk factors" for a zone.

Spatial risk factor :

$$A_{spatial} = \frac{\sum_1^n expanded\ survey\ area + \sum overlapped\ area}{Total\ Zone\ Area}$$

Temporal risk factor:

$A_{temporal} = A_{overall\ temporal}$ * % *Activity Area in Zone,* where

$$A_{overall\ temporal} = \frac{\sum_1^m Activity\ Days}{Days\ within\ Analysis\ Period}$$

Activity index:

$$A_{overall-zone} = A_{spatial-zone} + A_{temporal-zone}$$

Next, a Spectral risk factor ("Spectral index") te is calculated from the spectral content ratio of a gene source and species-specific hearing times the abundance and distribution of each species at a define (*e.g.*, 10km x 10km) spatial resolution.

Spectral risk factor:

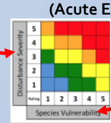
$$Spectral\ Index = \frac{Energy\ in\ M\text{-}weighted\ spectrum}{Energy\ in\ unweighted\ spectrum} * \ Abundanc$$

Finally, an Exposure Index is calculated as a function of the Activity Index and Spectral Index as mapped over a defined spatial grid within a zone over time period (e.g. month, year, years) so as to include relevant aspects of both aggregate anthropogenic activities and exposed species:

$$Exposure\ Index = A_{overall\text{-}zone} * Spectral\ Inde$$

Species-specific exposure values are then normalized based on the proportion of total region population within the zone and evaluated using a relativistic scori process in order to determine an associated aggregate risk score.

Behavioral Risk Assessment Matrix (Acute Exposure)

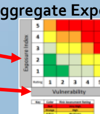


Key	Color	Adverse.Effects.Rating
	Red	Very High
	Orange	High
	Yellow	Moderate
	Green	Low
	Blue	Very Low

Risk Assessment – Species-Specific Vulnerability

Total Vulnerability Score (from factors 1-4)	Total Risk Probability (% of total possible)	Vulnerability Rating
24-30	80-100%	Very High
18-23	60-79%	High
12-17	40-59%	Moderate
6-11	20-39%	Low
0-5	0-19%	Very Low

Overall Risk Assessment Matrix (Aggregate Exposure)



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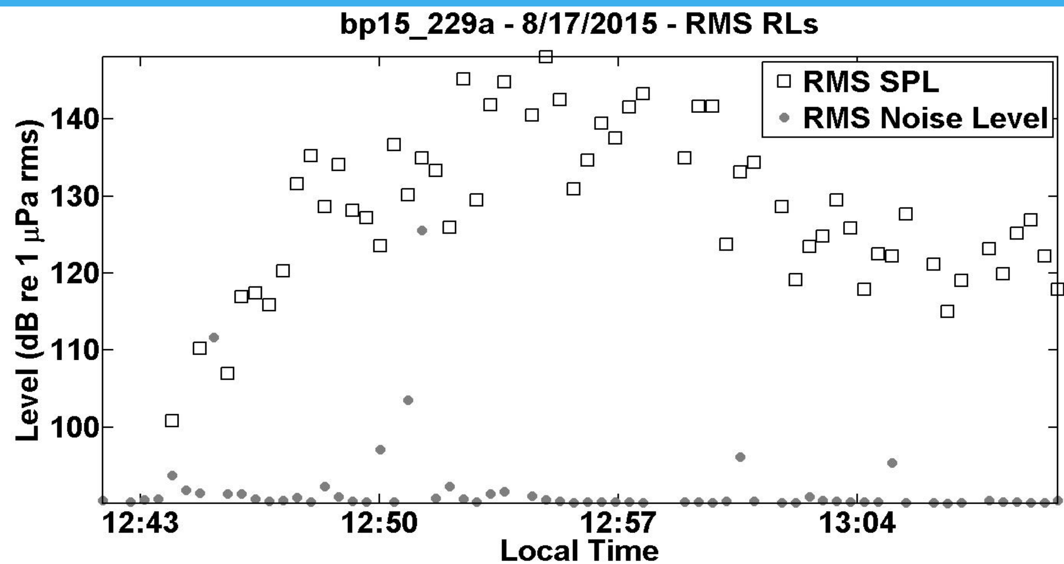
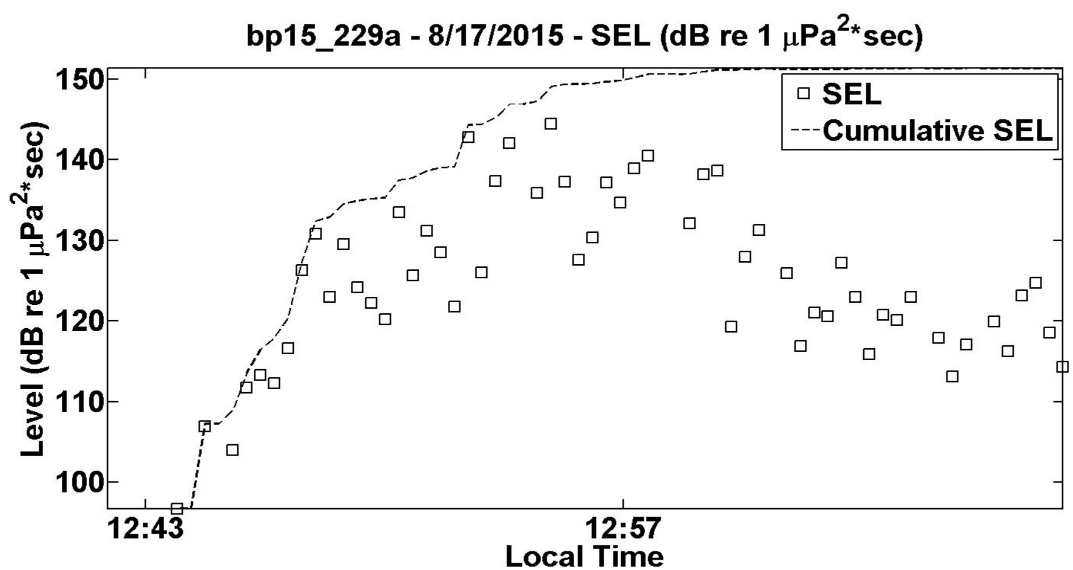
Different Metrics for Noise Exposure





New Research Frontiers in Marine Mammals and Noise

- **Increased focus on sub-lethal or sub-injurious effects**
- **Integrating physiological and behavioral response studies**
- **Advances anatomical modeling and AEP methods for species not present in labs**
- **Auditory and behavioral response studies using realistic (full-scale) sources**
- **Extending duration and resolution in field measurements of response (new tag technologies; BRS' on multiple scales)**
- **Integrate experimental and observational monitoring to increase sample size and duration and address strategic PCOD questions**