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

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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
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
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
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)
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.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Audiometry</th>
<th>Ear Type</th>
<th>Auditory modeling</th>
<th>Sound Production</th>
<th>Click type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Physeter macrocephalus</em></td>
<td></td>
<td></td>
<td></td>
<td>SOC: 0.4 (squeal) to 9 kHz (coda)</td>
<td>MP</td>
<td>Audiometry: No data Anatomical models: No data Acoustic: (Backus &amp; Schevill, 1966; Levenson, 1974; Watkins &amp; Schevill, 1977, 1980; Watkins, 1980; Weilgart &amp; Whitehead, 1988; Goold &amp; Jones, 1995; Madsen, Wahlberg, et al., 2002, Madsen, Payne, et al., 2002; Møhl et al., 2003; Weir et al., 2007)</td>
</tr>
<tr>
<td>Sperm whale</td>
<td>-</td>
<td>physysteroid middle ear</td>
<td>type I cochlea</td>
<td>ECH: 3 to 26 kHz</td>
<td>FM</td>
<td></td>
</tr>
<tr>
<td><em>Ziphius cavirostris</em></td>
<td></td>
<td></td>
<td></td>
<td>ECH: 28 to 47 kHz</td>
<td>FM</td>
<td>Audiometry: No data Anatomical models: No data Acoustic: (Frantzis et al., 2002; Zimmer et al., 2005; Baumann-Pickering, McDonald, et al., 2013)</td>
</tr>
<tr>
<td>Cuvier's beaked whale</td>
<td></td>
<td>physysteroid middle ear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>goose-beaked whale</td>
<td></td>
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<td></td>
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<tr>
<td><em>Delphinapterus leucas</em></td>
<td></td>
<td></td>
<td></td>
<td>SOC: 0.1 (whistle, pulsed calls) to 21 kHz (whistle, pulsed calls)</td>
<td>BBHF</td>
<td>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 &amp; 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 &amp; Wiersma, 1981; Sjare &amp; Smith, 1986; Au et al., 1987; Turl et al., 1991; Belikov &amp; Bel'kovich, 2001, 2005, 2006, 2007; Karlsen et al., 2001; Rutenko &amp; Vishnyakov, 2006; Lammers &amp; Castellote, 2009; Chmelnitsky &amp; Ferguson, 2012)</td>
</tr>
<tr>
<td>Beluga</td>
<td></td>
<td>odontocete middle ear</td>
<td></td>
<td></td>
<td>BBHF</td>
<td></td>
</tr>
</tbody>
</table>
Revised noise exposure criteria:
Hearing, weighting functions, TTS/PTS Onset
Approach and Outcomes

(1) Segregate all marine mammals into hearing groups.

<table>
<thead>
<tr>
<th>Marine Mammal Hearing Group</th>
<th>Auditory Weighting Function</th>
<th>Genera (or species) Included</th>
<th>Group-Specific Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low-Frequency &amp; Low-Frequency Cetaceans</td>
<td>LF</td>
<td><strong>Balaenidae</strong> (<em>Eubalaenidae</em> spp.; <em>Balaena mysticetus</em>); <strong>Balaenopteridae</strong> (<em>Balaenoptera musculus, B. physalus</em>); <strong>Balaenopteridae</strong> (<em>Balaenoptera acutorostrata, B. bonaerensis, B. omurai, B. edeni, B. borealis; Megaptera novaeangliae</em>); <strong>Neobalenidae</strong> (*Caperea); <strong>Eschrichtiidae</strong> (<em>Eschrichtius</em>)</td>
<td>1</td>
</tr>
<tr>
<td>Mid-Frequency &amp; High-Frequency Cetaceans</td>
<td>HF</td>
<td><strong>Physeteridae</strong> (<em>Physeter</em>); <strong>Ziphidae</strong> (<em>Berardius</em> spp., <em>Hyperoodon</em> spp., <em>Indop��etus, Mesoplodon</em> spp., <em>Tasmacetus, Ziphius</em>); <strong>Delphinidae</strong> (<em>Orcinus</em>)</td>
<td>2</td>
</tr>
<tr>
<td>Very High-Frequency Cetaceans</td>
<td>VHF</td>
<td><strong>Phocoenidae</strong> (<em>Phocoena</em> spp., <em>Neophocaena</em> spp., <em>Phocoenoides</em>); <strong>Iniidae</strong> (<em>Inia</em>); <strong>Kogiidae</strong> (<em>Kogia</em>); <strong>Lipotidae</strong> (<em>Lipotes</em>); <strong>Pontoporiidae</strong> (<em>Pontoporia</em>); <strong>Delphinidae</strong> (<em>Cephalorhynchus</em> spp.; <em>Lagenorhynchus cruciger, L. australis</em>)</td>
<td>3</td>
</tr>
<tr>
<td>Sirensians (SI)</td>
<td>SI</td>
<td><strong>Trichechidae</strong> (<em>Trichechus</em> spp.); <strong>Dugongidae</strong> (<em>Dugong</em>)</td>
<td>4</td>
</tr>
<tr>
<td>Phocid Carnivores in Water (PCW)</td>
<td>PCW</td>
<td><strong>Phocidae</strong> (<em>Cystophora, Erignathus, Halichoerus, Histriophoca, Hydrurga, Leptonychotes, Lobodon, Mirounga</em> spp., <em>Monachus, Neomonachus, Ommatophoca, Pagophilus, Phoca</em> spp., <em>Pusa</em> spp.)</td>
<td>5</td>
</tr>
<tr>
<td>Phocid Carnivores in Air (PCA)</td>
<td>PCA</td>
<td><strong>Phocidae</strong> (<em>Cystophora, Erignathus, Halichoerus, Histriophoca, Hydrurga, Leptonychotes, Lobodon, Mirounga</em> spp., <em>Monachus, Neomonachus, Ommatophoca, Pagophilus, Phoca</em> spp., <em>Pusa</em> spp.)</td>
<td>5</td>
</tr>
<tr>
<td>Other Marine Carnivores in Water (OCW)</td>
<td>OCW</td>
<td><strong>Odobenidae</strong> (<em>Odobenus</em>); <strong>Otariidae</strong> (<em>Arctocephalus</em> spp., <em>Callorhinus, Eumetopias, Neophoca, Otaria, Phocarctos, Zalophus</em> spp.); <strong>Ursidae</strong> (<em>Ursus maritimus</em>); <strong>Mustelidae</strong> (<em>Enhya, Lontra feline</em>)</td>
<td>6</td>
</tr>
<tr>
<td>Other Marine Carnivores in Air (OCA)</td>
<td>OCA</td>
<td><strong>Odobenidae</strong> (<em>Odobenus</em>); <strong>Otariidae</strong> (<em>Arctocephalus</em> spp., <em>Callorhinus, Eumetopias, Neophoca, Otaria, Phocarctos, Zalophus</em> spp.); <strong>Ursidae</strong> (<em>Ursus maritimus</em>); <strong>Mustelidae</strong> (<em>Enhya, Lontra feline</em>)</td>
<td>6</td>
</tr>
</tbody>
</table>
(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):

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

- \( T_0 \) 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)

* 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:

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

- \( C \) 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:

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

- \( K \) 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)**

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

Approach and Outcomes

(3) Auditory exposure functions
(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

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

### TTS & PTS onset: Impulsive Exposures

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

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**STAGE I: Sound Source**
- Type of Survey
- Technical Specifications
- Survey Site Distribution: Temporal and Geographic

**STAGE II: Marine Mammals**
- Identification: Marine Mammal Distribution/Density Data
- Quantify Marine Mammal Density/Population, By-Area Average

**STAGE III: Noise Exposure**
- Acoustic propagation modeling (i.e., source/environmental inputs)
- Animal movement modeling (integrate exposure with species-typical behavioral parameters)

**STAGE IV: Estimate Effects**
- Determine Extent of Injury/Adverse Exposures to Peak & SEL Criteria
- Determine Extent of Disturbance/Context and Species-Relevant Criteria (RMS SPL)

**STAGE V: Risk Assessment**
- Determine Extent of Injury/Adverse Exposures to Peak & SEL Criteria
- Determine Extent of Disturbance/Context and Species-Relevant Criteria (RMS SPL)
- Population Affected, Total Period of Disturbance, Adverse Effect Assessment

**STAGE VI: Assessment of Overall Conclusion**
- Injury Severity Exposure
- Potential Disturbance Adverse Effect
- Operational/Environmental/ Biological Uncertainty
A Risk Assessment Framework to Evaluate the Potential Relative Effects of Noise on Marine Mammals

1Southall Environmental Associates, Inc., 9099 Soquel Dr. #8, Aptos, CA 95003, USA, 2 Institute of Marine Sciences, Long Marine Laboratory, University of California, Santa Cruz, 3 Marine Acoustics, Inc., 4 SMRU Consulting, 5 Cornell Bioacoustics Research Program

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

**Aggregate Exposure Risk Assessment**

- Species-Specific Exposure Magnitude (“Exposure Index”)

**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*
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 Environmental Associates, Inc., 701 S. Ocean Blvd. #500, Aptos, CA 95003, USA, 1 Institute of Marine Sciences, Long Marine Laboratory, University of California, Santa Cruz, 3 Marine Acoustics, Inc., 4 SRI Consulting, 5 Correll 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., 2013), several of the authors have begun 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 context variables within a population context. The resulting risk assessment framework (Elison et al., 2015) was influenced by a number of important emerging conclusions from the past several decades of science on these issues (e.g., Clark et al., 1996a, 1996b, 2001; Southall et al., 2007). 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 level should be considered.
- The geographic scales for noise impact assessments should be broadly 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 biologically-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 context 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 ship operating situations) 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 overall risk assessment framework evaluated the relative magnitude and duration of the potential sensitivity within a population perspective using population consequences of disturbance (PCD) 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 moderate 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 event within the context of injury and behavioral exposure. 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.
Different Metrics for Noise Exposure

bp15_229a - 8/17/2015 - RMS RLs

Level (dB re 1 μPa rms)

Local Time

bp15_229a - 8/17/2015 - SEL (dB re 1 μPa²·sec)

Level (dB re 1 μPa²·sec)

Local Time
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