Early Progress and Challenges in Assessing Cumulative Sound Exposure and Associated Effects on Marine Mammals

Arctic Open Water Meeting
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*Representing the “Cumulative Effects” WG
Shifting Paradigms in the Assessment of Acoustic Exposure

• Recognition of a need to assess possible effects of cumulative exposure to multiple anthropogenic activities on marine mammals:
  – Science
  – Regulators
  – Industry

• Typically assessments of multiple anthropogenic underwater sounds:
  – examine effects of sound sources individually
  – rely on qualitative descriptions
  – are not systematic evaluations

• Need to expand current assessment to include:
  – Cumulative sound field from multiple sources
  – Ecologically-meaningful spatial/temporal scales
  – Chronic effects
A “Working Group” (WG) Approach

- Provide funding by industry (BP)
- Manage WG through independent contract
- Convene an “expert committee”
- Contract specifies academic freedom
- Hold series of general and specific workshops (6 during 2010-2013.)

Objective of WG:

→ To advance the development of systematic, quantitative and qualitative methods for estimating cumulative acoustic impact.
→ Test these methods on a case study.
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Creative Solutions to Difficult Problems require a Diverse Team

Expertise in: physical acoustics, marine and terrestrial mammalogy, statistics, risk assessment, hearing physiology, and assessment of cumulative effects.

Affiliations: universities, government agencies, nonprofit organizations and private sector.

- Bill Streever (BP)
- Erica Fleishman (UC Davis)
- Chris Clark (BRP/Cornell)
- Bill Ellison (MAI)
- Adam Frankel (MAI)
- Roberto Racca (JASCO)
- Robyn Angliss (NMML)
- Robert Suydam (NSB)
- Matthias Leu (WM)
- Samantha Simmons (USMMC)
- Megan McKenna (NPS)
- Melania Guerra (BRP/Cornell)
- Brandon Southall (SEA-Inc.)
- Darlene Ketten (WHOI)
- Dan Costa (UCSC)
- Jessica Lefevre (AEWC)
- Barry Noon (CSU)
- Jason Gedamke (NOAA)
- Bob Pressey (James Cook U)
- Joel Berger (UM)
- Todd Sformo (NSB)
- Len Thomas (U St. Andrews)
Conceptual Steps of a Quantitative Method for assessing Cumulative Exposure

1. Identify region, time period and species-of-interest;
2. Compile operational and acoustic data on multiple anthropogenic activities;
3. Model continuous and impulsive sound fields ("acoustic footprints") for each activity and for all activities combined (cumulative);
4. Collect information on natural behavior and avoidance response for species-of-interest;
5. Simulate animal movements through individual and cumulative acoustic sound fields;
6. Calculate estimates of acoustic exposures for each simulated animal and movement data, with and without avoidance response.
Step 1: Identify the region, time period and species of interest

Case Study is loosely based on events from Open Water Season 2008:

• Where?
  → Western Beaufort Sea, AK

• When?
  → 1 Sept. to 23 Oct. 2008

• Who?
  → Bowhead whales

Scenario presents spatial and temporal overlap of multiple O&G operational activities with bowhead Fall migration!
Step 2: Compile Operational Data on Co-occurring Anthropogenic Activities

Who is out there?
Where were there significant sources of sound?
Focus on sources most likely to contribute to the cumulative acoustic footprint.

Figure credit: R. Racca (JASCO)
Step 2: Compile Operational Data on Co-occurring Anthropogenic Activities

When were those sources active?  
What were they doing?  ➔ Continuous or impulsive noise?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Dates of Activity</th>
<th>Characterization of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northstar production island</td>
<td>1 September-23 October</td>
<td>Routine production with vessel support</td>
</tr>
<tr>
<td>Construction of Oooguruk production island</td>
<td>1 September-23 October</td>
<td>Construction with vessel support</td>
</tr>
<tr>
<td>Offshore barge tow</td>
<td>1 September-23 October</td>
<td>Generic barge tow typical of Beaufort Sea</td>
</tr>
<tr>
<td>Nearshore barge tow</td>
<td>1 September-23 October</td>
<td>Generic barge tow typical of Beaufort Sea</td>
</tr>
<tr>
<td>Offshore seismic exploration in Harrison Bay</td>
<td>3-September and 1-9 October</td>
<td>Seismic work, seismic work, and post processing</td>
</tr>
<tr>
<td>Offshore seismic exploration in Camden Bay</td>
<td>14-29 September</td>
<td>Seismic work, seismic work, and post processing</td>
</tr>
<tr>
<td>Nearshore seismic exploration 1</td>
<td>1-5 and 20-28 September</td>
<td>Seismic work, seismic work, and post processing</td>
</tr>
<tr>
<td>Nearshore seismic exploration 2</td>
<td>1-28 September</td>
<td>Seismic work, seismic work, and post processing</td>
</tr>
<tr>
<td>Nearshore seismic exploration 3</td>
<td>6-19 September</td>
<td>Seismic work, seismic work, and post processing</td>
</tr>
</tbody>
</table>

Table from Streever et al., 2012
Step 3:
Model continuous and impulsive sound fields (individual and cumulative)

Using JASCO’s Parabolic Equation propagation model. Frequency-dependent computation.

Figure credit: R. Racca (JASCO)
Step 3:
Model continuous and impulsive sound fields (individual and cumulative)

Assumptions and Simplifications:
• Sound sources are stationary
• Sound sources are omni-directional
• Seismic airgun surveys either off or full array:
  • Mitigation gun not modeled
  • No consideration of inter-pulse reverberation and/or reflections
• $SPL_{rms} = SEL + 10\text{dB}$, regardless of range to source (for impulsive sounds)

⇒ Models can handle more complex inputs, more realistic parameters.
⇒ We chose to begin with a simplified scenario.
Step 4:
Collect information on natural behavior and avoidance response for bowheads

Sources: Traditional knowledge, airborne surveys, satellite tags, etc.

- Migration “waves” – weekly groups
- Migration routes – offshore vs. nearshore
- Dive and surface durations
- Dive depths
- Heading variance
- Range of speed
- Range of depth
- Probability of avoidance behavior

→ Empirical observations will inform simulated ‘animats’ in Step 5.
Step 5:  
Model simulated whales (‘animats’) swimming through predicted acoustic footprints

AIM = Acoustic Integration Model

AIM Screen shot of 6 migrators passing seismic operation [SL=223dB @1m], showing their path and avoidance of SPL levels higher than 160dB.
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Model simulated whales (‘animats’) swimming through predicted acoustic footprints

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AIM Screen shot of 6 migrators passing seismic operation [SL=223dB @1m], showing their path and avoidance of SPL levels higher than 160dB.

Animation credit: W. Ellison (MAI)
Step 6:
Aggregate exposure and movement data & visualize results

Exposure history for an ‘animat’ swimming far from shore.

170dB SEL @48hrs.
From large seismic airgun array

Ambient background ~100dB

Figure credit: W. Ellison (MAI)
Step 6: Aggregate exposure and movement data & visualize results

Exposure history for an ‘animat’ swimming far from shore.

170dB SEL @48hrs. From large seismic airgun array

135dB SEL @77hrs. From small seismic airgun array

Ambient background ~100dB

Figure credit: W. Ellison (MAI)
Step 6: Aggregate exposure and movement data & visualize results

Exposure history for an ‘animat’ swimming close to shore.

- 140dB SEL @ 38hrs from large seismic airgun array
- Ambient background ~100dB
Step 6:
Aggregate exposure and movement data & visualize results

Similar acute exposures = 140dB SEL
@ 38hrs from large seismic airgun array
@ 68hrs from small seismic airgun array

Ambient background ~100dB

Exposure history for an ‘animat’ swimming close to shore.

Figure credit: W. Ellison (MAI)
Exposure histories provide insight into chronic exposure from multiple sources.

Whale 1: Offshore
Acute assessment = 175dB

Whale 2: Nearshore
Acute assessment = 140dB

Old paradigm: Regulate based on a single number (acute exposure)
Exposure histories provide insight into chronic exposure from multiple sources

Considering CHRONIC exposure, both whales were exposed to:

- >120dB for > 60hrs.
- >140dB for > 15hrs.

Consistently about 15-20dB above ambient background

New paradigm: Consider cumulative exposure over long term (chronic)
Exposure histories provide insight into chronic exposure from multiple sources

Other method outputs:

- Impact of aversion vs. no aversion on exposure
- “Whale odometer” – distance traveled with/without aversion

Figure credit: W. Ellison (MAI)
Accomplishments 2010-2013

• 6 general working group meetings held:
  • Santa Barbara, CA – May, 2010
  • Anchorage, AK - 2010
  • Barrow, AK – Apr. 28-29, 2011
  • Anchorage, AK – Oct. 18-20, 2011
  • Seattle, WA – Apr. 25-27, 2012
  • Seattle, WA – Feb. 5-7, 2013

• Various subgroups have also met independently
• Quantitative method developed and trial completed
• 2 internal reports written
• Peer-review paper is being drafted
• Multiple public presentations, briefings, panels, conferences.
Where we are...

What this method is...

• A first, positive step toward understanding the assessment of cumulative noise exposure.
• Work in progress.
• Needed and timely because anthropogenic activities will only increase.

What this method is NOT...

• A final method:
  – Future work could build on current method:
    • add complexity,
    • test different case studies,
    • address impacts, etc.
• Does not produce a single output metric.
• Does not make management decisions.
The Way Forward

Lessons Learned and Issues to address:

1. Insights on input variables and identification of data gaps
2. Critical need for spatial and temporal dynamics for all individual sound sources (sound source verification)
3. Challenges of assessing impulsive and continuous sounds simultaneously
4. Modeling requires simplification/assumptions
5. Modeling does not address masking potential
6. Model does not include considerations of elevated noise levels between impulses as a result of reverberation and reflections
7. Consequences of avoidance behaviors
8. Histories of individual modeled animals offer insights
Many thanks!

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- Christopher Shock
- Lisanne Aerts
Questions?

Thank you!