An overview of a simulation approach to assessing environmental risk of sound exposure to marine mammals.

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Outline

- Motivation
- Agent-based model overview
- Sensitivities
- Simulation scenarios
- Findings
- Conclusions
Motivation

- Proliferation of off-shore wind farms.
- Concerns about effects of noise on marine fauna – particularly during installation (pile-driving and drilling).
- A number of tools for investigating the effects of sound on marine fauna already developed in the context of SONAR (3MB, NEMO, ERMC).
- Interest in the long-term cumulative effects of installations on local animal populations – these tools are being employed e.g.:
  - A variety of installation scenarios off UK coast already assessed.
  - BOEM’s recent RFP “Acoustic Propagation and Marine Mammal Exposure Modeling of Geophysical Sources in the Gulf of Mexico” – ten year planning for seismic survey noise impacts.
Motivation

- Many of the tools are agent-based simulations.
- The underpinnings are broadly similar across tools.
- Given similar inputs/parameterisations, expect similar results (in short term scenarios).
- Hence similar sensitivities in terms of inputs and parameterisations (ie the results/conclusions are altered to different extents by the perturbation of the inputs).
- We’ve conducted a series of simulation studies that investigate some key parameters that are subject to debate.
- The intention is to identify modelling decisions that are influential on results, but may not be transparent to end users.
Model overview - SAFESIMM

- Individual/agent-based system, simulating individual animals moving through time, accumulating sound.
- SAFESIMM\(^1\) – the set of R-based code that was replicated for the commercial BAE Systems Instye product ERMC(S)\(^2\).
- Principal Development 2005-2007, continuing modifications to present.
- Substantial constraints in original remit: very little time permitted for calculations and on low-spec computing.
- Commercial version has a full GUI similar to ESME, whereas SAFESIMM is largely a research tool with no user-friendly front/back-end.

1. Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna
2. Environmental Risk Mitigation Capability (Sonar)
ERMC(S) front/back-end

- Commercial version has a full GUI similar to ESME, whereas SAFESIMM is largely a research tool with no user-friendly front/back-end.
Model overview - SAFESIMM

- Horizontal Density Module
- Horizontal Movement
- Dive Module
- Movement Modification
- Probability of Effect, Affected Marine Mammals
- Accumulated Effect
- Sound Propagation
- Biological Consequence Module

Iterate through time if required

Final Results
Model overview - SAFESIMM

- Horizontal Density Module
- Horizontal Movement
- Dive Module
- Movement Modification
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Final Results
Model overview - SAFESIMM

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- Horizontal Movement
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Iterate through time if required

Final Results
Model overview - SAFESIMM

- Individual/agent-based system, simulating individual animals moving through time, accumulating sound.
- Simulation animals are distributed in space and move through time.
- Calls to sound fields are made periodically – animals may respond (in movement) depending on parameterisation.
- SELs are calculated.
- Physical effects (TTS/PTS) determined stochastically via dose response relationships. Behavioural dose responses have been used.
Model overview - SAFESIMM

- Simulated animals move on the surface, dive and resurface.
- Vertical and horizontal movement may be modified by exposure, depending on species specific parameters.
Simulation scenarios

Two species considered: grey seal (*Halichoerus grypus*) and harbour porpoise (*Phocoena phocoena*). Three broad areas looked at:

- Comparisons of SEL weightings: audiogram & M-weighted (Southall *et. al.*, 2007)
- Comparisons over levels of “fleeing” behaviour
- Site-fidelity: constrained versus unconstrained long term movement.
## Simulation scenarios

### 10 day exposure periods, 1kHz, 225dB re 1 $\mu$Pa source

| Audiogram weighting versus M-weightings | No aversion versus varied aversion levels | Long-term movement constraints e.g. site fidelity |
|----------------------------------------|------------------------------------------|------------------------------------------------|
| Audiogram weighted SEL and PTS threshold at 95dB above auditory threshold (>8 hrs) | No response to sound | Freedom of movement over exposure |
| Southall et al M-weighted SEL and associated PTS thresholds | Increasingly directed response to sound (away) via precision on directed random walk. | Site fidelity that constrains animals to be within 75 – 100km of source (e.g. tolerate exposures circa 140dB re 1 $\mu$Pa) |
Broadly two methods for adjusting received sound levels for differing sensitivity to frequency.

- Southall et al (2007) M-weights
- Audiogram – estimated auditory threshold functions (oft referred to as $dB_{ht}$)

(Weighted) SELs then linked to physical effects e.g. Permanent Threshold Shift (PTS)

- Southall et al (2007) M-weighted SEL have accompanying PTS thresholds
- Audiogram weighted SELs have various possibilities: infer from few dose-response studies (e.g. Finneran et al 2005).
Audiogram-weightings vs M-weightings

![Graph showing comparison between Audiogram-weightings and M-weightings](image-url)
Audiogram-weightings vs M-weightings

Simulations consisted of:

• Two species, 10 day exposure scenarios tracking 10,000 simulated animals.

• SELs and levels of induced PTS under:
  – M-weighting and Southall et al thresholds
  – Audiogram weightings and use Heathershaw et al (2001) link to PTS (95 dB above auditory threshold after 8 hr exposure).
Audiogram-weightings vs M-weightings
Audiogram-weightings vs M-weightings

Percentage of simulated animals exceeding PTS threshold under differing weighting and threshold schemes.

| Weighting | PTS threshold (dB) | Scenario length (hrs) |
|-----------|-------------------|----------------------|
|           | 1 | 6 | 12 | 24 | 48 | 96 | 168 | 240 |
| Grey seal |   |   |    |    |    |    |     |     |
| Audiogram | 166 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Southall M | 186 | 0.3 | 6.9 | 12.3 | 16.4 | 18.1 | 20.1 | 23.7 | 27.3 |
| Harbour porpoise |   |   |    |    |    |    |     |     |
| Audiogram | 175 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Southall M | 198 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
Level of responsive movement (avoidance)

Simulations consisted of:

- Grey seals, 10 day exposure scenarios tracking 10,000 simulated animals.
- 1kHz, 225 dB re 1 μPa source
- M-weighting and Southall et al thresholds
- Directed random walks with varying levels of directionality away\(^1\) from the source.

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1. Variance parameters on a wrapped Normal distribution which determines the direction of the next movement – the mean direction of the distribution is away from the source.
Level of responsive movement (avoidance)
Constrained/unconstrained movement (site fidelity)

Simulations consisted of:

- Grey seals, 10 day exposure scenarios tracking 10,000 simulated animals.
- 1kHz, 225 dB re 1 μPa source
- M-weighting and Southall *et al* thresholds
- Simulations conducted over varying aversion to sound (zero in the following example).
- One scenario is unconstrained movement, the other has a hard boundary at 75km from source ~140dB.
Constrained/unconstrained movement (site fidelity)
Key points

Regarding sensitivities (physical effects – PTS):

• Short-term versus long-term scenarios have different sensitivities.
• Choice of weightings M-weights vs. audiograms can be markedly different under any length scenario.
• Whether responsive movement is specified or not has little influence in short scenarios (e.g. 6 hour). Differences can be marked on the order of days.
• Relatedly, site fidelity has little influence in short scenarios (e.g. 6 hour), differences become marked on the order of days.

[NB. Species density maps are not considered, but are *a priori* a large sensitivity and poorly known]
Key points

• Long-term exposure scenarios are not likely to be consistently addressed under the common agent-based models i.e. results may be very divergent based on qualitative decisions e.g. levels of site-fidelity, “fleeing”.

• Risk assessments for the same scenario can be very different based on the weighting scheme employed – this may be opaque.

[NB mitigation requires that scenario assessments be at least relatively correct, if not absolutely correct]
“Priorities”

In order of the sensitivities considered here – assessment by agent-based models:

- [Density maps – not considered here].
- Weighting & thresholds.
- Site-fidelity, particularly for long-term assessment. Post/During exposure: Do they stay? Do they return? How long until they do?.
- Responsiveness to sound, particularly for long-term assessment.
- [recovery – not considered here but another notable aspect for long-term assessments]
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“always end on a pretty picture” apparently