Developing the next generation framework for modelling marine mammal responses to noise

a workshop to identify key elements for future models

Saana Isojunno, Catriona Harris, Len Thomas and Peter Tyack

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Introduction

A full-day workshop was held at the World Marine Mammal Conference in Barcelona, Spain, on the 8th December 2019. The objective of the workshop was to discuss how marine mammal responses to noise could be modelled in the future to reduce uncertainty in dose-response, better capture biological significance and improve estimates of impact. A theme throughout the day was context-dependent responses to noise. The role of context was explored from auditory, behaviour, physiology, and population consequence perspectives in several different talks. Break-out group discussions aimed to identify what context variables may be the most relevant versus practical to measure in order to improve upon noise impact assessments that rely on acoustic exposure alone as the dose parameter. The afternoon session of the workshop focused on identifying key elements for future models and horizon scanning. For a detailed agenda, please see Supplement A. Agenda.

The workshop was organized as part of the Double Mocha project, led by teams at the University of St Andrews (Len Thomas, Catriona Harris, Richard Glennie) and Duke University (Rob Schick, Alan Gelfand). The overall aim of the project is to develop new quantitative models and analytical methods for inferring behavioural responses of marine mammal species to Navy sonar. This is being addressed under three sub-tasks: 1) Develop analytical methods that allow fusion of multiple input datasets collected across a range of spatial and temporal scales in behaviour response studies, 2) Develop recommendations for effects analysis of long-term passive acoustic data, and 3) Develop next-generation models for behavioural response based on our understanding of marine mammal signal detection and the evolutionary drivers of response. The workshop aimed to directly inform into the third task by gathering interdisciplinary feedback on what the next generation framework may look like. Task 3 also includes conducting a review of contextual variables affecting responses to navy sonar. The results of the review were presented at the workshop and are also below. Ultimately Task 3 will develop mathematical and statistical models based on a new proposed framework and assess model sensitivity to input parameters.

The workshop was attended by 8 speakers and 74 other participants, representing a broad range of stakeholders from academia to regulatory bodies. Participants included representatives from governments, industries, the military, non-governmental organisations, environmental consultancies, as well as a broad range of academics, including students. Besides the oral presentations, over a dozen participants contributed poster presentations under three broad themes: context-dependent responses to noise, linking individual responses to population-level consequences, and modelling techniques. Please see below for the poster titles, authors and abstracts.

Management perspectives

To help guide the workshop by policy and management needs, we gathered feedback from representatives from several management, regulatory, and advisory bodies, and summarized them in an introductory presentation (Supplement C). The represented bodies included US National Oceanic and Atmospheric Administration (NOAA), US Bureau of Ocean Energy Management (BOEM), Marine Mammal Commission, Marine Scotland, and the German environmental agency. We asked each representative to contribute: A) 2-3 key challenges that regulators face when making management decisions based on the current available science and models, in particular when extrapolating to data-poor areas or species, and B) 2-3 wish-list items that would allow regulators to include more than RL thresholds in their assessments.

The contributions aligned to several common themes. Dose-response relationships were highlighted as important but still poorly understood components of decision-making. Decision-making was also

stated to be challenging in data poor areas where the application of the precautionary principle can lead to 'compound precaution' in regulation, particularly for industrial activities in offshore areas. When new information or data does become available, it can be challenging to incorporate quickly without being too reactionary. Listed challenges also included a lack of a standard approach for incorporating uncertainty. Important contextual variables were identified (e.g., migration vs. feeding, mother-calf pairs, source-animal range) as well as the requirements for them to be included in assessments in the future (e.g., further data, quantitative methods). All representatives touched on the challenge of identifying significant impacts and the need to define biologically meaningful responses. Related to this, the representatives called for a framework to assess cumulative impacts which would incorporate animal exposure history across multiple activities. For further details and direct quotes, please see Supplement C.

Empirical evidence for context in sonar response studies

In advance of the workshop, a literature review was conducted to assess the empirical evidence for context-dependent responses of marine mammals to navy sonar. Much of the relevant literature has been reviewed relatively recently in several papers (Gomez et al. 2016; Southall et al. 2016; Harris et al. 2017), and while context was discussed therein, no reviews have explicitly focused on it. These reviews and several conceptual frameworks (Ellison et al. 2012; Erbe et al. 2016; National Academies of Sciences, Engineering 2017) emphasize the likely importance of context in not only mediating the probability of responses, but also severity and consequences of responses. Several hypotheses have been put forward. The Ellison et al (2012) framework proposes that context-dependent responses are more likely at lower received acoustic dose. NAS (2017) predict lower severity of noise impact when the predictability of the noise source is high, onset of the noise signal is slow, and when the noise signal has relatively low resemblance to biologically relevant (e.g., predator) sounds. Factors that influence signal transmission and reception (e.g., hearing group, ambient noise levels) are also expected to be important (Erbe et al. 2016).

Papers were selected using a systematic search of the Pub Med and ISI Web of Science literature databases. The search string was specified following Gomez et al 2016, but with the noise sources limited to navy sonar: "((marine mammal) or (whale) or (dolphin) or (porpoise) or (pinniped) or (cetacean) or (seal) or (sea lion)) and (navy or naval or military) and (sonar)". The resulting papers (Pub Med: 100 documents, ISI: 298) were screened for suitability, defined as empirical studies that quantified responses of live marine mammals to navy sonar. This definition excluded papers that were based on simulated data alone, works that focused solely on noise field characterization, review papers, and studies that only considered prey or baseline behaviour. Finally, several papers that were not returned through the systematic search were added from the recent review papers (Gomez et al. 2016; Southall et al. 2016; Harris et al. 2017) and by repeating the search from within the journal Aquatic Mammals (using Google Scholar). After removing duplicates, the selection resulted in 69 articles.

The following information was extracted from each paper: noise source type (frequency range, sweep type(s)), study species, measured responses, tested context variables, and whether any support was reported for the context variables (positive/negative/no effect). Two types of context variables were considered: 1) 'baseline context' variables that influence the response metric of interest independent of whether the animal is exposed to the noise or not, vs. 2) 'true context' variables that influence the responsiveness or type of responses during sonar exposures alone, or depending on the exposure characteristics. For example, prey availability would be classed as a baseline context variable if it influenced the heart rate or diving behaviour of an individual both

during baseline and exposure treatments. On the other hand, if prey availability influenced the probability that the individual responded or habituated to sonar, then it would be considered as a true context variable. Because the same animal or a group of animals could be exposed to the same sounds multiple times, the degree of independence between samples was highly variable between studies. Therefore, no attempt was made to summarize a sample size for each study. Each paper could test several context variables, and therefore the unit of analysis was a report/test of a context effect. Please see Supplement D for the resulting data tables.

A total of 126 reports were recorded from 55 papers that tested context effects. 32 reports came from controlled exposure experiments (CEEs) on captive subjects and 64 from CEEs on free-ranging animals. Opportunistic exposures were included in 30 reports; 19 of these came from purely observational work. The majority of the reports (82) tested effects of simulated navy sonar at the 1-10 kHz band, and most reports concerned behaviour responses (N=97). The most commonly supported context variables were also those that were most often reported: behaviour state prior to exposure (12/19=0.63), order effects (10/16=0.63), signal frequency band (confound with source level in some studies; 12/16=0.75) and signal sweep type (e.g., up vs. down sweep; 4/6=0.67). Frequently reported and supported context variables also included inter-annual variation (4/6=0.67) and diurnal effects (5/6=0.83). Most reports that tested order effects supported greater effects at first exposure (N=9); two reported the opposite, and 5 reported no effect of order. Furthermore, captive studies on bottlenose dolphins and Californian sea lions support a reduced responsiveness with increasing age (Houser et al. 2013a; Houser et al. 2013b; Houser et al. 2016). Prey field was found to influence baseline foraging behaviour (Croll et al. 2001; Kuningas et al. 2013; Friedlaender et al. 2016). Most studies inferred prey-mediated responses (true context effect) from behaviour context or a combination of prey field measurements and behaviour responses (Southall et al. 2019). There was no clear support for the effect of specific signal types. For example, the effect of up vs. down-sweep signals depends on how responses are measured, illustrating that context effects can be different on hearing vs. behaviour (Kastelein et al. 2011; Kastelein et al. 2012; Kastelein et al. 2014).

The review highlighted both strengths and data gaps in the empirical literature. In particular, experimental testing of order effects has demonstrated that cetaceans tend to reduce behaviour responsiveness to repeat navy sonar exposures. However, with the overall lack of non-auditory physiological measurements, it is possible that this tolerance does not translate to physiological habituation. Direct measurements of prey field are also lacking, for odontocetes especially, which would help contextualize behaviour responses. In order to link behavioural responses to individual fitness, further empirical work is required at the individual level, for example investigating the effect of age, reproductive status and body condition on responses. Meta-analyses that combine data from multiple studies will be needed to obtain the sample sizes required to test such individual context variables. This further underlines the importance of comprehensive reporting of noise response studies, including number of independent vs. dependent samples, and negative vs. positive results. Presenting negative results is crucial so that future systematic reviews can quantify relative support for context variables.

Summary of participant feedback

Context variables

The first interactive session of the day aimed to identify context variables that should be included in response modelling from three different perspectives: 1) variables that are thought to influence the probability of a response, 2) variables that are thought to influence the type of response (avoidance, group redistribution, cessation of foraging, etc) and therefore the link to fitness/ biological

significance, and 3) variables that are realistic and available for implementing mitigation or guiding decision making. The participants were provided paper forms to conduct the scoring and were asked to identify a study system to which the context variables would apply. The participants were asked to fill the forms first individually and then in pairs or groups to reach a consensus scoring. Forms were digitized if they were either clearly labelled as consensus, or they were likely to represent consensus because they matched one of the four pre-defined study systems (see the next section).

The context variable scoring resulted in 11 digitized consensus forms (Supplement E). In this sample, two of the study systems were unspecified and two were generalized (multiple species), while the rest were scored specifically for beaked whales (2), medium-sized odontocetes (1), baleen whales (2), and harbour porpoises (2). The majority of the forms identified the following context variables as important in mediating the probability of response: source-whale range (N=8), received sound exposure level (SEL) (N=7), resource context and prey field (N=7), subject species (N=6) and behaviour context (N=6). Resource context and prey field were the most frequently scored context variables to influence type of response (N=8). Source approach was the most frequently scored context variable to influence type of response, but not probability of response (N=3).

The context variables most frequently ranked as available for mitigation or decision making included source-whale range (N=8), source characteristics (e.g., source level, N=5) and species (N=5). Resource context and prey field was the most frequently scored context variable to influence probability (N=4) and type of response (N=5), but *not be available*. There was also a discrepancy between the availability vs. scored importance of source approach (N=3) and individual health status (N=3) in determining response types.

Key elements in different study systems

The second interactive session of the day aimed to identify key elements for future models and begin drafting the next generation framework. Each participant was assigned a group with a specific study system according to the participants' background, as much as possible. The eight groups were: 1-2) Deep divers, 3) Medium-sized odontocetes in semi-pristine environment, 4) Medium-sized odontocetes in more impacted area, 5) Baleen whales in high latitudes, 6) Baleen whales in low latitudes, and 7-8) Harbour porpoise in the North Sea. Each group comprised around 10 participants. The groups were given an hour to work on their frameworks, which were then presented to the whole group, followed by an open discussion.

The two 'Deep divers' groups discussed frameworks for beaked whales. The first group identified the need for multiple temporal scales and long-duration measurements. Their concept model included four key elements: acoustics (source level, range), environment (arrangements of animals, habitat preferences, ecological change), physiology, and reproductive & vital rates (calving rates, inter-calf intervals). The second group also identified exposure duration, temporal pattern and source range as important, but also mentioned multiple stressors in the 'disturbance' component of their graphical model. The individual context in this model included stage-based demography (age structure, fecundity, mortality), linked to energetics, and activity budgets linked to prey field. The individual and disturbance effects were then depicted to scale up to population-level consequences through a home range kernel.

The two 'Medium sized odontocetes' groups discussed low and high-impact areas respectively. The low-impact group focused on belugas in Greenland as an example and identified a combination of disturbances that would be important to include in a future dose-response framework: multiple types of vessel activity (commercial ships, tourism, hunting boats) and vessel noise (contributing to auditory masking), as well as climate change impacts in the region. In their model, environmental

change affected the species of interest through redistribution of their predators, prey and subsequent impacts on individual energetics and body condition. Mother-calf pairs were identified as important and vulnerable in terms of both energetics and susceptibility to masking of communications sounds. The high-impact group focused on short-finned pilot whales off Cape Hatteras. The group identified the following key elements: acoustic exposure (SEL, duration, frequency), source-to-whale range, environment (prey, other conditions), and behaviour context. Regarding the signal type, the group identified harmonics and similarity of the signal to predator sounds as important.

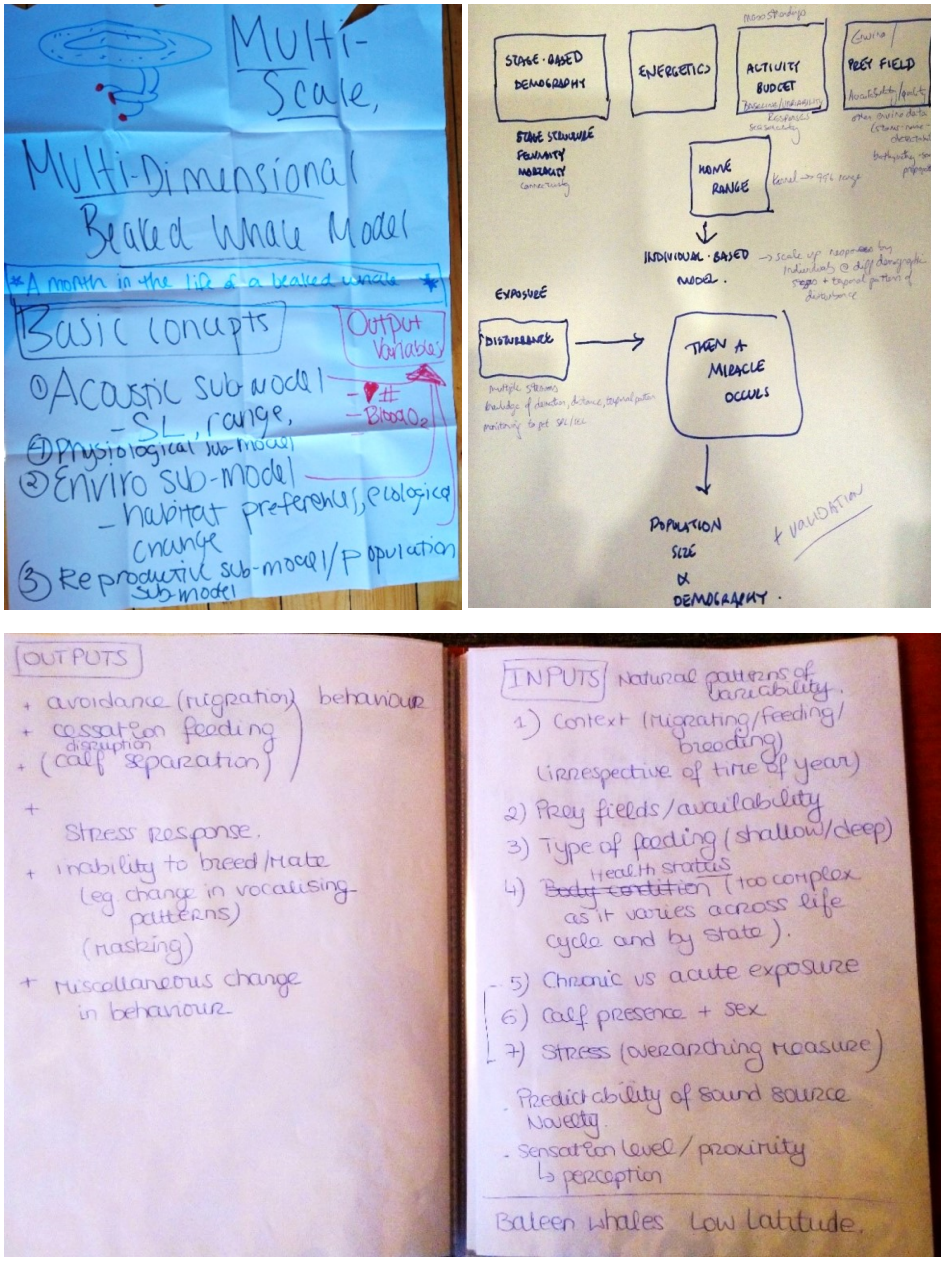

Fig. 1. Some ideas collected from the break-out group work

Of the two baleen whale groups, the 'High latitude' group focused on individual energetics on foraging grounds. This group envisioned their model output to be body condition, which would then allow linking individual responses to the population level. The input variables of this model included three key predictors of foraging behaviour 1) spatiotemporal distribution of prey (although lack of information on this was noted), 2) received level and measured soundscapes, when available, and 3)

life history information. The 'Low latitude' group considered the study system latitude to be not as important as the animals' ranging patterns and migration routes. The group discussed the potential for umbrella terms that, by summarizing several sources of data and variation, could be more cost-effective to include in models. For example, sensation level and signal excess could capture several factors influencing signal reception (e.g., hearing group, ambient levels). Similarly, umbrella terms for individual health status, such as body condition or stress levels, could be used. The group nevertheless identified a range of important model inputs: broad-scale behaviour context (migrating/feeding/breeding), prey field/availability, type of feeding, health status and stress levels, chronic vs. acute exposure, as well as calf presence and individual sex. Different response types were listed as the model outputs (avoidance, cessation of feeding, calf separation, stress response, inability to breed/mate, other changes in behaviour).

Both of the 'Harbour porpoise in the North Sea' groups discussed how to best measure acoustic exposure to predict responses, and what the responses would then mean to the animals in terms of foraging energetics. The first group identified loudness and masking as key components of acoustic disturbance. In the part of their model that described the impact on the individual, the group identified prey availability (abundance and types), site fidelity, energetic thresholds for reproduction, ability to compensate, and prey responses to noise as important aspects to be considered. The second group also discussed energy budgets, which could be informed by DTAG data including respiration rates, and prey availability. In addition, the group identified time of year and time of day (or light levels) as important environmental context variables. For the exposure context, the second group included signal-to-noise, predictability of source movement (e.g., shipping vs. recreational boating) and a pooled metric for multiple anthropogenic activities (shipping, marine renewables).

Open discussion

The open discussion at the end of the day revolved around 1) the challenges that regulators and managers face when implementing the complex science behind marine mammal responses to noise, and the fact that uncomfortable generalisations are necessary; 2) how to incorporate exposure history (cumulative exposure) in models and what are the appropriate temporal scales (acute vs. chronic); 3) how to best pool species in species groups – should we use a-priori functional hearing groups, some ecological groupings, or use an empirical approach to determine groups through model selection?; 4) striking the right balance between model fit and complexity: capturing variance in dose-response functions vs. including a greater number of context variables when there is generally not sufficient data to cover all the different context variable combinations.

Conclusions and next steps

Several common elements emerged across the four different study systems, but not all were considered as readily available or even possible to include in mitigation or other decision-making. The common elements included received acoustic dose and exposure duration, individual energy budgets and status at different life/reproductive stages, resource context and prey availability, as well as integrating impacts of multiple disturbance sources in the environment. Broad behaviour contexts (e.g., feeding/breeding/migration) and habitat preference/ site fidelity were included in most draft frameworks, with migration specifically more relevant for baleen whales. In terms of exposure context, source-whale range emerged as both important and available in most consensus forms returned by the groups. By contrast, resource context and prey availability were identified as often not available for mitigation or decision-making.

The next step of the project is to draft a conceptual next generation framework based on the discussions held at the workshop and the literature review presented here. The model will include

the key identified elements and some 'uncomfortable but necessary generalisations' in a mathematically explicit structure. We envision this model to include multiple hierarchical levels to capture several processes that predict responses, with outputs that can inform both probability and severity of responses.

Acknowledgements

We would like to thank all speakers (Brandon Southall, Lori Schwacke, Nicola Quick, Elizabeth Henderson, Enrico Pirotta and Peter Tyack) for their time and invaluable contributions to the workshop. We are also grateful to contributors of the management and policy perspectives (Tiffini Brookens, James Price, Jolie Harrison, Ewan Edwards, Carol Sparling, Mirjam Mueller) and to all workshop facilitators who ensured constructive discussion and feedback throughout the day (Philippe Bouchet, Sarah Marley, Andy Read, Douglas Nowacek, Petter Kvadsheim, as well as all the speakers who also volunteered in this task).

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Supplementary material

A. Agenda
B. Posters
C. Management perspectives (Powerpoint file)
D. Literature review data tables (Excel sheet)
E. Digitized consensus forms (Excel sheet)

Supplement A. Agenda

Session 1: Role of context in marine mammal responses to noise

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08:40 Catriona Harris & Saana Isojunno: Introduction with regulatory/management perspectives

09:00 Brandon Southall: Noise exposure criteria – emergent conclusions for auditory thresholds to broader issues

09:15 Lori Schwacke: Non-auditory physiological responses to sound and considerations for context dependence

09:30 Nicola Quick & Andy Read: Role of context in marine mammal behaviour responses to noise

09:45 Saana Isojunno: Context-dependent responses to navy sonar: a brief review of data

10:00 Break & posters

Session 2: Incorporating context in models

10:30 Liz Henderson: Marine Mammal Behavioral Response Functions for Navy EIS Analyses

10:45 Catriona Harris & Len Thomas: Dose-response models, covariates and interactions

11:00 Enrico Pirotta: Integrating the results of behavioural responses studies into PCoD

11:15 Discussion, questions to presenters

11:30 *Interactive 1*: identifying context variables for biological relevance vs. practical use

12:30 Lunch

Session 3: The next generation framework

14:00 Peter Tyack: Introduction to the next generation framework

14:15 *Interactive 2:* Drawing models in groups, one broad study system per table

15:00 Break & posters

Session 4: Discussion & horizon scanning

15:45 Groups present the most important elements in their models

16:00 Chaired discussion

17:00 Close

Supplement B. Posters

Theme 1) Context-dependent responses to noise

Mom, can you hear me? Impacts of underwater noise on mother-calf contact in endangered belugas (Delphinapterus leucas)
Valeria Vergara, Jason Wood, Marie-Ana Mikus, Audra Ames, Veronique Lesage and Robert Michaud

Noise and anthropogenic disturbance from vessel traffic are an important threat to the recovery of the endangered St. Lawrence Estuary beluga population. The consequences of acoustic masking could be particularly adverse in the case of critical vocalizations that function to maintain contact between mothers and their dependent but mobile calves. This study modeled communication range of adult and newborn beluga contact-calls in the presence and absence of vessels in an important summering area for this population. Ambient noise measurements in the presence and absence of vessels, a composite beluga audiogram, and apparent source levels of adult and neonate beluga contact-calls informed the model. These first estimates of communication range of beluga vocalizations with a known function show that masking can be particularly problematic for the quiet calls of neonates.

Physiological and behavioural responses of wild harbour porpoises to a commercial acoustic deterrent device
Siri L. Elmegaard, Jonas Teilmann, Mark Johnson, Dennis Brennecke, Lonnie Mikkelsen, Magnus Wahlberg, Ursula Siebert and Peter T. Madsen

We investigate fine-scale physiological and behavioural responses of harbour porpoises to a commercial acoustic deterrent device (Lofitech, Norway) in Danish waters. Porpoises bycaught in pound nets were tagged with suction cup-attached DTAGs recording electrocardiogram, sound, and movement (GPS, depth, 3D-accelerometry, 3D-magnetometry). Released animals were exposed to the deterrent device for 15 minutes, receiving levels of 83-138 dB re 1µPa RMS, corresponding to sound source distances up to 15 km at sea, assuming spherical spreading. They responded with increased fluking effort and speed, decreased echolocation output and heart rate acceleration while breath-holding, thus impairing echolocation acuity and potentially blood gas management.

Animal Exposure Modeling: From Dives and Turns to Context
Adam S. Frankel, Kathleen Vigness-Raposa, William T. Ellison and Jennifer Amaral

The methods for predicting animal acoustic exposure have made great strides since their creation nearly two decades ago (Ellison et al., 1999). The fundamental approach is to simulate animal movement through space and time, which is convolved with an acoustic field to produce a predicted acoustic exposure time series (e.g., Frankel et al., 2002). Initially, these outputs were analyzed to produce simple energy domain metrics that were compared against regulatory thresholds. Later, temporal domain metrics were developed that considered additional aspects such as the duration of exposures (Frankel and Gabriele, 2017). Analysis tools are continuing to be developed that ingest these exposure histories to produce additional interpretations, as well as expand the spatial and temporal duration over which the simulations occur. In this poster we will analyze animal exposure estimates in a context-dependent framework to highlight the importance of context as an additional factor in assessing impact to marine mammal behavior (Ellison et al., 2012).

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Quantifying individual manatee exposure to watercraft disturbance using GPS and long-term acoustic tags

Julia R. G. Dombroski, Susan E Parks, Monica Ross and Mark Johnson

Exposure data are key to estimate cumulative effects disturbance on individuals and populations. Florida manatees are exposed to recreational boat traffic throughout their habitat where collision with watercraft is the primary cause of mortality and boats are known to disturb behavior. However, the cumulative effects of boat disturbance on the species are unknown because limited information is available on the exposure experienced by individuals. To quantify individual exposure to boat traffic, we deployed DTAG-4s on manatees. Combining the acoustic record from the tag with GPS data, we hope to quantify spatial and temporal exposure to produce individual-based exposure maps with estimates of disturbance by boat traffic on manatees.

Effects of Continuous Active Sonar (CAS) vs. traditional pulsed sonar (PAS) on sperm whale behaviour; latest result of the 3S3 project

Frans-Peter Lam, Saana Isojunno, Petter Kvadsheim, Paul Wensveen, Sander von Benda-Beckmann, Charlotte Curé and Patrick Miller

The 3S project (Sea Mammals, Sonar, Safety) has conducted behavioral response studies since 2006, and started its third phase (3S3) in 2016. Worldwide there is a trend to extend the duration of sonar transmissions up to (almost) continuous transmission schedules. Performance of Continuous Active Sonar (CAS) is promising, with the capacity to achieve similar or better sonar performance than the traditional Pulsed Active Sonar (PAS) and with reduced source level. See e.g. Van Vossen et al. (2011). However, the impact of CAS on marine mammals is mostly unknown. In 2016 and 2017 we compared behavioral responses of sperm whales in northern Norway to PAS and CAS signals. We found that in this study the time budget of the exposed sperm whales was modified by the sonar signals (more time with non-foraging behavior), and this could be quantified with the overall sound exposure level (SEL), supporting sound energy over amplitude as the response driver.

Theme 2) Linking individual responses to population-level consequences

Using Dynamic Energy Budget Models to Assess the Impact of Disturbance on Life History and Population Dynamics of Medium-Sized Cetaceans

Vincent Hin, John Harwood and André de Roos

We present a Dynamic Energy Budget (DEB) model for a medium-sized cetacean, the long-finned pilot whale Globicephala melas. This DEB model is a continuous-time energetic model in which life history unfolds from the balance between energy intake through resource and milk feeding and energy loss through lactation, gestation, metabolism and growth. Because DEB models are process-based, they account for the multiple pathways in which disturbance can affect population growth, such as delayed age at first reproduction, decreased survival of females and calves and increased inter-birth interval. Furthermore, we elevate the DEB model for a single female to the population level to study the population consequences of disturbance in a density-dependent context.

Predicting the impacts of anthropogenic disturbances on marine populations
Jacob Nabe-Nielsen, Floris M van Beest, Volker Grimm, Richard M Sibly, Jonas Teilmann and Paul M Thompson

Anthropogenic disturbances can influence animal movements, energetics, and fitness, and ultimately also the dynamics of marine populations. Here we present a process-based modeling framework, DEPONS, for assessing population consequences of such behavioral effects. The framework incorporates realistic animal movements and assumes that animals' tendency to move away from a sound source is proportional to the received sound level. The framework was developed to assess effects of wind farm construction noise on the North Sea harbor porpoise population but is applicable to a wide range of species.

Effects of disturbances on the population dynamics of a marine predator: The importance of seasonal variation in energetics
Cara A. Gallagher, Volker Grimm, Line Kyhn and Jacob Nabe-Nielsen

Seasonality in mammals has evolved as a method of navigating the complex interaction between the integrated evolutionary and homeostatic responses of organisms to physical and biological variables and this seasonality can cause vulnerability to anthropogenic disturbance to vary throughout the year. However, predicting the impacts of disturbance on a population requires an understanding of how disturbance affects the physiology, energetics, and fitness of individuals. Here we present a mechanistic, spatially realistic individual-based energetic modeling framework for simulating the effects of human disturbance on marine populations. We use the model to evaluate the effect of anthropogenic noise from seismic surveys on a species that has been noted to have exceptionally high metabolic costs, the harbor porpoise, *Phocoena phocoena*. The impacts of disturbance were found to vary seasonally with the largest impacts occurring during the late summer and fall months. This framework serves as a novel approach to evaluate the threat of disturbance both seasonally and spatially to identify not only where but also when a disturbance may most endanger a population, allowing for better informed spatial planning and mitigation of disturbance effects.

Theme 3) Modelling frameworks & other topics

Visualization of Spatially-Explicit Acoustic Layers in an Underwater Soundscape
Kathleen J. Vigness-Raposa, Adam S. Frankel, William T. Ellison and Jennifer L. Amaral

New science suggests improvements are needed to the simplistic regulatory approaches that define exposure using single source/single species absolute received levels. Modern approaches should integrate and require measurements that synoptically evaluate biologically relevant exposure metrics (e.g., loudness, signal-to-noise ratio, sensation level) and consider spatial, spectral, and temporal contexts of exposure (e.g., behavioral state, prey fields, and proximity and encroachment parameters). New approaches to managing the overall acoustic scene that account for these metrics require more holistic and multi-dimensional approaches that address the relationships among noise environment, animal hearing and behavior, and anthropogenic sound sources. We present a layered approach that considers each facet of the exposure scenario in a spatially-explicit manner.

The Navy Acoustic Effects Model (NAEMO): Adapting to Changing Requirements.
Christina A. Wertman, Tara E. Moll, Benjamin R. Colbert, Stephanie L. Watwood and Peter H. Hulton

We utilize the Navy Acoustic Effects Model (NAEMO) to quantify impacts of naval sonar activity on marine species . We demonstrate the viability of using this model to analyze spatial and temporal contributions of naval activities on habitats and sound-scapes. This model allowed for the

identification of the proportion of the habitat above relevant thresholds providing a consistent degradation index for activity comparison.Areas in acoustic habitats are idenitified where individuals could incur physical or behavioral impacts as well as where masking and communication space loss would occur. Quantifying degradation of acoustic habitats can help with future environmental planning and strategy.

Behavioral Effects of Sound on Marine Mammals: Quantification of Trends in Study Methods and Results and Inter-Reviewer Biases
Sarah Courbis, Alexandria Loureiro, Robert Gisiner, Dagmar Fertl and Aude Pacini

To minimize impacts of sound on marine mammals, develop effective mitigation, and ensure legal compliance, it is important to understand potential responses to sound. One way to integrate information is literature review. Literature review can also examine inconsistencies in publications and assess inter- and intra-reviewer differences. We evaluated >200 publications, reports, and unpublished sources on behavioral effects of sound on marine mammals. We quantified inconsistencies and reviewer bias. Preliminary results show trends in differences. For example, testing single variables without consideration of context (such as environmental conditions) or controls can lead to different conclusions than multi-variate types of analyses. Understanding these issues allows for critical consideration when applying literature to decision-making. Finally, this review confirmed that reviewer bias, even among experts, is a likely and quantifiable factor in literature review.

Quantifying behavioural responses of minke whales to sonar activity during Navy training exercises.
Catriona M. Harris, Steve W. Martin, Cameron Martin, Tyler A. Helble, E. Elizabeth Henderson, Glenn Ierley, Ian Durbach, Charles Paxton and Len Thomas

Analysis of acoustically-derived minke whale tracks from before, during and after naval sonar activities indicates redistribution of calling whales during sonar exposure. Cessation of calling or a horizontal movement response?

Accounting for Positional Uncertainty When Modeling Received Levels for Tagged Cetaceans Exposed to Sonar
Robert Schick, Matthew Bowers, Stacy DeRuiter, Ari Friedlaender, John Joseph, Tetyana Margolina, Douglas Nowacek and Brandon Southall

Failure to accounting for positional uncertainty when modelling behavioural response to sound can result in biased assessment of received level (RL). In some cases within the Cape Hatteras BRS, we estimated the range of possible RLs for a single animal in a single exposure to be greater than 40 dB. This uncertainty in received level is critical to parameterizing dose-response relationships between marine mammals and anthropogenic sound. Using satellite tags with considerable positional uncertainty results in broad estimates of received level; however, their continued use is critical to collect movement and diving behaviour over longer time and space scales.