ESOMM - 2018

6th International Meeting on the Effects of Sound in the Ocean on Marine Mammals

The Hague, The Netherlands

9 - 14 September 2018

Conference organizers:
Frans-Peter Lam (TNO)
Marije Siemensma (Marine Science & Communication)
René Dekeling (NL Defence Materiel Organisation)
Koen Bröker (JIP)

Contents

1 Introduction

This 6th International Meeting on the Effects of Sound in the Ocean on Marine Mammals (ESOMM) in The Hague, the Netherlands, brings together scientists that study the effects of sonar, to share their research results with operational users and regulators and show how to improve management and regulation of sonar systems based on science. The knowledge shared during ESOMM will support military operators who need to ensure responsible use of naval sonar systems.

However, we need to look further than the Navy sector, and it has been the tradition of previous ESOMM conferences to bring together different communities. Not only the military community has worked on the management and understanding of the effects of underwater sound on the marine environment. Other sectors, especially the off-shore energy sector - both the oil and gas producers and the renewable energy sector - has made significant investments on this topic, and we would like to encourage the exchange of knowledge between these different communities. Therefore, the organisation of ESOMM is pleased to combine the ESOMM meeting with the 3rd Programme Review Meeting (PRM) of the E&P Sound & Marine Life Joint Industry Programme (JIP).

Cooperation between communities is becoming more urgent with the European Marine Strategy Framework Directive (MSFD) and the NOAA Ocean Noise Strategy; regulators and policy makers realize the need to address the effects of all relevant sound sources. To address cumulative effects in the future we need to combine knowledge across sectors. In the joint ESOMM/JIP-2018 meeting, representatives of different communities will come together. This provides an excellent opportunity to discuss the important role of sound science in policy- and regulation development and environmental management.

In order to better understand and mitigate impacts of anthropogenic sound on marine life, it is of key importance to use all relevant information and identify and prioritize knowledge gaps, so relevant research can be commissioned and communicated. In addition to this, it's also critical to bring together the relevant stakeholders to share insights and develop sustainable solutions. We are looking forward to a successful week with informative and fruitful cross-sector stakeholder discussions.

Frans-Peter Lam, TNO
Marije Siemensma, Marine Science & Communication
René Dekeling, Ministry of Defence, The Netherlands
Koen Bröker, JIP

2 Programme outline

ESOMM/JIP-2018

6th International Meeting on the Effects of Sound in the Ocean on Marine Mammals (ESOMM)
&
the 3rd Programme Review Meeting (PRM) of the IOGP E&P Sound & Marine Life Joint Industry Programme (JIP)

Sunday 9 September

- Icebreaker and registration at the Carlton Beach Hotel Scheveningen - 17.00-19.00

Poster Programme

- Posters are on display during all breaks from Monday to Friday next to the plenary room

Monday 10 September

- *Registration and coffee - 08.00*
- Formal opening of the meeting by the Royal Netherlands Navy
- Welcome and introduction by organizers; Opening and Scope of ESOMM/JIP-2018
- International Policy & Regulation Developments
- *Break*
- International Policy & Regulation Developments continued
- *Lunch break*
- JIP Overview
- *Break*
- New developments
- *Reception at Carlton Beach Hotel (closing 19.00)*

Tuesday 11 September

- *Coffee - 08.00*
- JIP Morning Session: Behavioral Responses & Population Consequences of Disturbance
- *Break*
- JIP Morning Session: Behavioral Responses & Population Consequences of Disturbance (cont'd)
- *Lunch break*
- Behavioural Response Studies in the Field (BRS)
- *Break*
- Behavioural Response Studies in the Field (BRS) (cont'd)
- *Closure – 17.00*

Wednesday 12 September

- *Several optional outdoor activities (Beach yoga, boot camp, guided dune walk)*
- *Coffee – 09.30*
- JIP Morning Session: Physical & Physiological Impacts
- *Lunch break*
- Behavioural Response Studies in the Field (BRS) (cont'd)
- *Break*
- Continuous sound sources
- *Closure – 17.20*

Thursday 13 September

- *Coffee – 08.00*
- JIP Morning Session: Monitoring & Mitigation
- *Break*
- JIP Morning Session: Monitoring & Mitigation (cont'd)
- *Lunch break*
- PAM-DCL- Monitoring & Density Estimation
- *Break*
- Population Effects
- Management & Regulation Discussion
- *Closure – 17.00*
- *Departure for Dinner (timing to be confirmed)*

Friday 14 September

- *Coffee – 08.00*
- JIP Morning Session: Sound Source Characterisation & Propagation
- *Break*
- JIP Closing Session
- *Lunch Break*
- Standards, Hearing Physiology & Stress Responses
- *Break*
- Hearing Physiology & Stress Responses
- Closing of plenary programme ESOMM/JIP-2018 -17.00

3 Abstracts ESOMM-2018

An international terminology standard for marine bioacoustics

Topic
All topics

Sound source
General (all sources)

Ainslie, Michael A. (1), de Jong, Christ A. F. (2), Halvorsen, Michele B. (3), Morfey, Christopher L (4), Laws, Robert M. (5)

Analysis of the effects of noise on aquatic animals requires an understanding of how these animals generate, detect and use biologically relevant signals. In the past, scientists and engineers from different disciplines have developed their own distinct jargons, making it difficult to communicate between disciplines without misunderstandings. A combination of regulation and ethical concern for aquatic animals has generated both the need and the will for scientists from different disciplines to communicate with one another. We describe a tool that facilitates effective communication by defining a common language for all: the international standard ISO 18405:2017 Underwater Acoustics – Terminology. Standardization of acoustical terminology in air began in the 1940s, and today the jargon of airborne acoustics is widely accepted for noise impact assessments, as consolidated in national and international standards. By comparison, underwater acoustical terminology lags about 60 years behind. ISO 18405 provides, for the first time, a set of internationally accepted definitions for terms in widespread use such as sound pressure level, sound exposure level, source level, transmission loss, propagation loss, echolocation click, hearing threshold, hearing threshold shift, frequency weighting function, detection threshold, ambient sound, ambient noise and many more. The definitions are distinct, unambiguous and applicable to all marine fauna, including marine mammals, fish, turtles and invertebrates. ISO 18405 and the process that led to the published definitions are summarized. The benefits of the standard are described in the context of specific examples of its use.

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A whale's dilemma; considering transboundary disparities of regulating impact to marine mammals from sound associated with offshore energy development
(Poster)

Topic
Policy Development and Other Stakeholder Perspectives

Sound source

Arzt, Tamara S., J.D., M.P.A. Environmental Protection Specialist, ESA/MMPA Lead

Regulating impacts to marine mammals from sound generated by offshore energy development is highly challenging within a single country. Achieving a coordinated transboundary regulatory effort of these impacts spanning nations is a seemingly insurmountable goal. Existing varied regulatory approaches to the same issue across jurisdictions can result in policies and decisions that may unduly burden the offshore energy industry and may not allow for the application of mitigation measures that best prevent unacceptable impacts to marine mammals that cross these jurisdictional boundaries.

Further complicating jurisdictional regulatory differences are regulatory schemes that were not created to address imperfect and/or lacking information as is the case with impacts to marine mammals from sound related to offshore energy development. For example, in the U.S., existing statutory and regulatory frameworks created to address clear impacts to marine mammals from commercial fishing lack the mechanisms and ability to effectively and efficiently provide a balanced application under the law that both protect marine mammals and allow for offshore energy development to move forward without undue burdens.

Examining different countries' approaches to regulating impacts from sound on marine mammals related to offshore energy development and coordinating across jurisdictions could allow for cross-border consistency. The goal of this endeavor could provide mitigation that would better benefit and protect marine mammals as they move throughout regions and potentially create more predictable and efficient permitting and planning processes for government agencies and the offshore energy industry resulting in reduced overall costs.

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Assessing exposure and response of three species of odontocetes to mid-frequency active sonar (MFAS) during Submarine Command Courses (SCC) at the Pacific Missile Range Facility (PMRF), Hawaii *WITHDRAWN*

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field

Sound source
Sonar

Baird, R.W. (1), Martin, S.W. (2), Manzano-Roth, R. (3), Webster, D.L. (1), Southall, B.L. (4)

Exposures and responses of short-finned pilot whales, rough-toothed dolphins and false killer whales to MFAS (~3-4 kHz) during US Navy Submarine Command Courses at PMRF were investigated using data from satellite tags and sonar operations. Received levels (RLs) were estimated using the Peregrine propagation model near the surface and at specified depths, accounting for known uncertainty associated with Argos locations. A tagged false killer whale was exposed to MFAS at ranges from 6.5-75.4km, moving from an area of relatively low (mean=91 dB re: 1 μPa RMS) to higher RLs (mean=160 dB). Three tagged rough-toothed dolphins exposed at 19.5-94.4km had maximum estimated mean RLs of 151-157 dB.
The individual with highest RLs moved into areas with the highest RLs. Two pilot whales exposed at 3.2-48.1km had relatively high RLs (mean=169, 168 dB). No large-scale movements away from areas with high RLs were observed. Dive rates for one tagged pilot whale exposed at levels up to 169 dB were lower during the day and night during the SCC compared to pre- and post-SCC periods. Day-time dive depths were significantly deeper during the SCC, while night-time dive depths were similar for all periods. Our results indicated no large-scale avoidance of areas with moderately high RLs during the SCC. However, clear behavioral changes were observed for the one individual with detailed dive data. All individuals were from resident populations. Given that MFAS is regularly used at PMRF and has been for many years, these individuals have likely been exposed repeatedly, potentially influencing their responses.

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Impact of mid-frequency active sonar on beaked whale echolocation from long-term passive acoustic recordings *(Poster)*

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field and Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking

Sound source
Sonar

Baumann-Pickering, S.[1], Trickey, J.S.[1], Širović, A.[1], Oedekoven, C.S.[2], Hildebrand, J.A.[1], Thomas, L.[2], Wiggins, S.M.[1], Roch, M.A.[3]

Behavioral response studies of tagged cetaceans have documented an adverse reaction to mid-frequency active sonar (MFAS). We examined long-term, passive acoustic data for acoustic behavioral response of Cuvier's beaked whales (*Ziphius caviostris*) to sonar operations in southern California, an area of frequent naval activity. Acoustic data were collected at four sites from 2006 to 2015. Recording effort at these sites varied between 674 and 2,284 days per site, resulting in 19 years of acoustic effort. Cuvier's beaked whale echolocation clicks occurred on average 4 to 44 daily cumulative minutes at these sites. There were 100,000s of sonar pings recorded with received levels ranging from ~100 dB_{pp} re: 1μPa up to recorder clipping level of 165 dB_{pp} re: 1 μPa.
The relationship between MFAS and the acoustic behavior of whales is complex and requires accounting for natural temporal and spatial variability in click densities which may be caused by *e.g.*, variability in seasonality, habitat preference, and individual variability. Generalized estimating equations (GEEs) were used to model relationships between click presence and temporal and sonar covariates. *Year,* describing inter-annual variability, and *julian day,* describing seasonality, were retained by the model as important variables. Probability of detecting beaked whales increased with increasing time since the last use of sonar up to about a week, and then remained stable. Several sonar-related covariates, such as received level, (cumulative) sound exposure level, and variability of these covariates over time, appeared negatively related to click densities, but were not retained by the best fit model.

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Humpback whales (*Megaptera novaeangliae*) can discriminate between the sounds of different killer whales (*Orcinus orca*) ecotypes *(Poster)*

Topic
Behaviour Response Studies in the field

Sound source
Killer whale sounds

Benti, Benjamin, (1,2,3), Miller, Patrick (2) & Curé, Charlotte (3)

Cetaceans' behaviour can be influenced by various sounds from their environment including heterospecific sounds. Behavioural responses to predator stimuli can serve as a template to interpret the biological relevance of responses to anthropogenic stimuli. However, interactions between killer whales (KW) and humpback whales (HW) range from coexistence to predation by some KW ecotypes, so HW responses to KW presentation may depend upon the ecotype of the KW that produced them. To assess whether HW can discriminate across KW ecotypes, we conducted playback experiments in northern Norway during the feeding season, both inshore (January 2016-2017, N=6) and offshore (June 2011-2012, N=8). We used familiar fish-eating KW (FEKW) sounds from northern Norway and unfamiliar mammal-eating KW (MEKW) sounds from southeast Alaska. Since both HW and FEKW feed upon herring, we expected FEKW sounds to elicit a 'dinner-bell' effect. By contrast, we expected MEKW sounds would be perceived as a potential predation risk. By using Dtags and visual tracking, we showed that HW approached the speaker and explored deeper water layers during FEKW playbacks whereas they clearly stopped feeding and swam horizontally away from MEKW sounds source. Moreover, HW exhibited shallower dives during and after MEKW playbacks offshore, whereas they dove deeper after MEKW playbacks inshore. Results show that cetaceans' behavioural responses can be radically different depending on the perceived biological context of detected heterospecific sounds, and that a careful selection of specific KW sounds is required to characterize the anti-predator behavioural template.

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Emissivity rules: Principles of infrared whale detection revisited

Topic
Monitoring for Marine Life

Sound source
General (all sources)

Boebel, O. (1), Burkhardt, E. (1), Cammareri, A. (2), Flau, M. (1), Ketten, D. (3,4), Zwicker, S. (1), Zitterbart, D.P. (1,3)

Thermographic (infrared/IR) imaging has been demonstrated repeatedly to reliably capture whale cues at mitigation relevant distances, including at night when visual observations are essentially futile.

IR performance may however be subject to environmental conditions as well as the observed species, as a cue's IR perceptibility requires a finite difference between cue and oceanic radiances, raising the question of to what degree this method is applicable globally.

Particularly for tropical and equatorial climates, a general concern exists that warm ocean water would reduce the contrast between cue and oceanic radiance because of a lesser temperature difference between the two.

Contrary to the underlying assumption that thermal contrast between cue and ocean governs the difference in radiance, our quantitative statistical analysis of 1900 cues demonstrates that the difference between oceanic radiance and both blow or body radiances is, to first order, constant, i.e. independent of the oceanic radiance, an observations also reported recently by Horton et al. (2017).

Our paper explores the extent to which this correlation is subject to global ambient radiances, angular emissivity and the aspect at which the ocean background and the cue are viewed respectively, i.e., glancing with low angular emissivity for the near horizontal ocean surface versus near perpendicular with high angular emissivity for body parts and blow droplet facets.

Notwithstanding the linear correlation between cue and ambient radiance, residual inter-cue variations in radiance suggest individual dependencies and thermodynamic processes modify cue radiance, aspects to be discussed with regard to their impact on the cue's IR perceptibility.

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Sensitivity and Directionality in the Peripheral Auditory System of Mysticetes

Topic
Assessment and mitigation software

Sound source
N/A

Cranford, Ted W. (1), Krysl, Petr (2)

Frequency sensitivity and directional characteristics of the sound reception apparatus are important survival factors for marine vertebrates. We developed the Vibroacoustic Toolkit (VATk), tools that allows us simulate and visualize the biomechanical processes comprising mysticete low-frequency (LF) sound reception. The VATk combines CT scan data with elastic tissue properties and finite element modeling (FEM) techniques. Mysticetes x-ray computed tomography (CT) scans, including an entire minke whale, were conducted using a scanner designed for rockets.

Our investigation used various finite element models, including the VATk, to produce three significant discoveries: (1) the first computational audiograms for two mysticetes, a fin whale and a minke whale; (2) evidence that mysticete skulls are part of the mechanism for LF sound reception; (3) LF sound reception in mysticetes is directional, but the mechanism(s) are unclear.

Minke whale pulsed sounds occur between 50 and 300 Hz, while the "boing" sounds occur between 1-2 kHz. The minke computational audiogram covers both ranges, but also includes a prediction of sensitivity between 10-40 kHz. This "high-frequency" sensitivity may offer some protection against killer whale predation.

The simulation technology we developed provides an innovative computational platform that untangled intricacies of baleen whale sound reception, as well as biosonar signal generation and beam formation in toothed whales.

Our hypothesis is that all cetacean heads function like acoustic antennas. Inputs to the ears are integrated over the entire surface of the head. Some surface areas contribute more than others, but there is no single "window" or bilateral channel for sound reception.

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Broad-Scale Acoustic Monitoring For Cetaceans And Underwater Noise In Relation To Offshore Wind Farm Construction In Scotland *(Poster)*

Topic
Monitoring for marine life

Sound source
General (all sources)

Culloch, Ross (1), Brookes, Kate (1), Bennet, Finlay (1) Edwards, Ewan (1), Merchant, Nathan (2) and Davies, Ian (1)

Marine construction projects, such as offshore wind farms and port developments often use techniques that produce significant levels of noise underwater, which could have effects on marine wildlife. Marine Scotland is the government body responsible for regulating these activities in Scottish waters and for ensuring that wildlife populations are protected in line with legislation.

Large scale offshore wind farm construction started off the Scottish east coast in 2017, using piled foundations. To monitor for potential broad scale changes in distribution of protected cetacean species during construction activities, Marine Scotland deployed an array of 30 click detectors and 10 broadband acoustic recorders across the Scottish east coast each summer since 2013. Here we present baseline distributions for dolphins and harbour porpoises, along with ambient noise levels recorded concurrently.

Dolphin detections across the monitored area are highly variable, with some locations that are clearly favoured. Harbour porpoise are ubiquitous and in more than 60% of locations are detected on 100% of monitored days. This is likely to mean that there is more power to detect changes in porpoise distribution in relation to offshore wind farm pile driving than for dolphins.

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Severity scoring sperm whales' behavioral responses to pulsed and continuous active sonar *(Poster)*

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Curé, C. (1), Isojunno S. (2), Siemensma M.L. (3), Wensveen P. (2, 4), Sivle L. (5), Benti B. (1, 2), Hansen R.R. (6), Kvadsheim P.H. (7), Lam F.P. (3), Miller P.J.O. (2)

This study is part of the 3S project (Sea-mammals Sonar Safety) investigating how naval sonar affects cetacean behavior. Besides the fact that naval sonars produce sounds at frequencies overlapping with the hearing of most cetacean species, they are generated at high power and their use has been linked to various stranding events. In previous works, we conducted controlled exposure experiments (CEEs) and showed that 1-2 kHz pulsed active sonar (PAS) induced costly behavioral responses in sperm whales (e.g. cessation of feeding), similar to an anti-predator response. Since then, new generations of active sonar generating continuous signals (CAS) are being developed to improve target detection. This raises further concerns about how CAS might affect cetacean behavior. To address this question, we conducted CEEs of 1-2 kHz CAS and PAS signals on sperm whales in Northern Norway, and we compared behavioural responses to both sonar types.
We inspected the behavioral data recorded by acoustic and movement data loggers (Dtag) and visual observations of the tagged whales at the surface, and we used the severity scale of Southall et al. (2007) to assign severity scores to putative behavioral responses elicited by the experimental exposures. A blind procedure was applied to ensure that any unconscious biases of the scoring panels did not result in differences between exposure types. The results will provide indications of the nature and/or severity of behavioral responses of sperm whales to PAS versus CAS sonars, and contrast any responses to the anti-predator template using previously published severity scores.

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Acoustic thresholds for marine piling noise in relation to behavioural disturbance of harbour porpoises and seals

Topic
Population-level and ecosystem level effects (PCOD and other) and Assessment and mitigation software

Sound source
Pile driving

de Jong, Christ (1), von Benda-Beckmann, Sander (1), Heinis, Floor (2), Erkman, Aylin (2)

The current guideline for environmental impact assessments and appropriate assessments for future Dutch offshore wind energy projects includes a comparison of the calculated levels of piling sound to which porpoises and seals are potentially exposed against threshold levels above which a significant behavioural response (e.g. avoidance) or noise induced hearing loss are expected to occur. A study is presented that addresses the question whether the assessments of effects of impulsive underwater sound on marine mammals in the North Sea can be improved by incorporating frequency weighting. The available literature on the application of frequency weighting has been reviewed. The available data from measurements and calculations of piling sound have been analysed, to evaluate the effects of different forms of frequency weighting on impact assessment and threshold levels. It is likely that an updated assessment on the basis of frequency-weighted levels would lead to a different prediction of the zone around a piling location where a significant behavioural response in porpoises and seals is induced than an assessment on the basis of unweighted sound exposure levels. The case on noise induced hearing loss is considered sufficient clear to advise the application of frequency weighting to calculate the area wherein TTS and PTS can occur. However, at this moment there is insufficient information to establish frequency weighted threshold values for behavioural responses. Further international collaboration is sought to enable development and international harmonization of frequency weighted thresholds for behavioural response.

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Overarching issues- cooperation between communities and international developments

Topic
Policy developments and other stakeholders perspectives

Sound source
General (all sources)

Dekeling, René

10 years ago, there was no national or European regulation that explicitly mentioned underwater noise as an environmental threat requiring management, although it was implicitly covered by overarching regulation, e.g. European directives or national law on environmental impact assessments. The European Marine Strategy Framework Directive (MSFD) of 2008 has brought a change, as it formally defines human-induced marine underwater noise as a pollutant and requires European Union member states to ensure that anthropogenic noise is at levels that do not adversely affect the marine environment. The Directive further requires European Union member states to address the effects at an ecosystem level and to ensure coordination in marine regions, leading to programs of measures that achieve or maintain good environmental status (GES) in all European seas.

International cooperation on monitoring of underwater sound has started in Europe, e.g. with a register for impulsive noise-generating activities in the North-East Atlantic region and in the Baltic Sea; joint monitoring programs for continuous noise have started and are likely to expand over the coming years. The noise registers will enable member states to bring together information on impulsive noise generating activities from different sectors. The aim of this approach is to look at cumulative effects of all impulsive noise generating activities, across borders, across sectors, over longer periods. Assessment methodology needs further development, but is it clear that knowledge from different sectors needs to be brought together to enable future management of underwater noise.

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Methods for collecting large samples of real sonar response data from Cuvier's beaked whales

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Falcone, E.A.(1), Schorr, G.S.(1), Watwood, S.L.(2), DeRuiter, S.L.(3), Rone, B.K.(1), Andrews, R.D.(1), and Moretti, D.J.(2)

Behavioral response studies have become important tools for investigating the effects some anthropogenic activities have on cetaceans. However, data resolution, contextual complexity, and small sample sizes can limit the interpretation of their results. To study their response to sonar exposure, we tagged 16 Cuvier's beaked whales on an active US Navy training range with medium-term LIMPET satellite tags that provided summarized movement and dive data. We combined tag data with concurrent records of actual sonar use, in effect creating Opportunistic Exposure Experiments (OEE). The resulting dataset included 4,867 hours of sonar-free behavior and 913 hours of sonar-exposed behavior. The durations of dives, surfacings, and deep-dive-intervals increased in the presence of sonar, and typically increased as distance to sonar decreased. Whales responded to mid-power sonar deployed from helicopters at lower received levels than high-power ship-based sonar, suggesting source type and context are also important response predictors. To address uncertainty in responses associated with the low spatial resolution and summarized dive data of the LIMPET tag, we began using higher resolution, GPS-enabled, dart-attached archival tags in 2017. These tags can remain attached up to 21 days, providing sufficient individual baseline data and the opportunity for multiple OEEs, based on the typical operational tempo on the training range. Additionally, we are conducting Coordinated Sonar Exposure Experiments (CSEEs) during these deployments, where real Navy platforms help to create specific exposure scenarios to provide data in contexts of interest.

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The Ecology of Human Sound Sources: Where They Live, Their Habits, and Why They Do What They Do *(Poster)*

Topic
Effects of sound on marine life

Sound source
General (all sources)

Gisiner, Robert C.

Our interest in manmade sound in the sea has focused almost exclusively on "megafauna": antisubmarine sonars; explosives; pile driving; seismic surveys; and commercial shipping. Yet these activities have different purposes or "niches" and different "behavioral ecology". Sonars and seismic surveys are "louder" than ships, but there are more than 52,000 active cargo ships and fewer than 500 ships equiped with either ASW sonars or seismic survey sources. The economics of shipping requires almost continuous operation and therefore almost continuous sound production. Seismic sources produce sound less than one percent of the time; sonars are used even less frequently. The "habits" of commercial ships are to move fast and in predictable straight lines. Submarine hunting requires the hunter to behave erratically, while seismic vessels move slowly (<1.5 m/s or 5 kts) in patterns akin to those of farm equipment. The "mice and ants" of manmade sound sources have been given little attention, in spite of an astonishing technology explosion in the use of sound sources for research, navigation, and deliberate ecological disturbance. Tens of thousands of Acoustic Deterrence Devices (ADDs and AHDs) are put into the water each year with little or no regulation or monitoring. Research vessels, including a growing fleet of unmanned vehicles, bristle with positioning systems, ADCPs, depth sounders, multibeam sonars, and more. Managing the marine soundscape will require us to develop better understanding of its soniferous "species", both mechanical and biological, and their respective niches, and ecosystem functions.

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Assessing risk from impact pile driving using the damped cylindrical spreading model *(Poster)*

Topic
Assessment and mitigation software and Sources and sound propagation

Sound source
Pile driving

Halvorsen, Michele B. (1), Ainslie, Michael A. (2), Lippert, Tristan (3), Müller, Roel (4)

Sound exposure level (SEL) and peak sound pressure level (Lpk) are used as correlates forassessing risk of injury to marine animals close to powerful underwater sound sources. For pile driving, it is common to measure the level close to the pile and extrapolate this measurement to distance (R) assuming the transmission loss (TL) takes the form of, for example, 15logR plus a zero decay rate, a form often applied, with widespread acceptance for propagation from a point source. However, a driven monopile does not resemble a point source, thus, alternatives are considered. Sounds generated by pile driving spreadcylindrically at first, at longer distance are damped exponentially because of multiple seabed interactions, leading to the term 'damped cylindrical spreading' (DCS). The DCS model involves 10logR plus a constant decay rate, while the German regulator Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) formula specifies 14logR plus a varying decay rate proportional to logR. Risk distances were estimated for a selected speciesusing three different approaches for TL: 15logR, DCS, and the BMU formula. The estimated risk distances were compared with measurement-based risk distances and both 15logR and BMU were found to overestimate TL for the cases considered. Overestimated TL leads to overestimated risk prediction between the pile and the measurement position, and underestimated risk prediction between the measurement position and 4 km from the pile. By contrast, DCS was found to estimate risk more accurately than either 15logR or BMU at all distances up to 4 km from the pile.

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Quantifying behavioural responses of minke whales to sonar activity during Navy training exercises.

Topic
Behaviour response study in the field

Sound source
Sonar

Harris, Catriona M. (1), Martin, Stephen W. (2), Martin, Cameron (2), Helble, Tyler A. (3), Henderson, E. Elizabeth (3), Paxton, Charles G. (1) and Thomas, Len (1)

The BREVE (Behavioral Response Evaluations Employing Robust Baselines and Actual Navy Training) project is an opportunistic exposure study, utilizing observations around real-world naval activities. The focus is on whale tracks derived from passive acoustic monitoring (PAM) on the Pacific Missile Range Facility (PMRF), Hawaii, whereby a track is defined as a series of localizations attributable to the same animal. The research has two components. First, we are working to establish baseline behaviours for multiple baleen whale species through processing existing datasets from PMRF. Second, we are extending and adapting methods for quantifying behavioural responses to sonar that were developed for data from controlled exposure experiments. We are using data from periods of Navy training to compare against baseline data. We will present results from a training activity on PMRF in February 2014. We have extracted 31 minke whale tracks from the period spanning the training, as well as 29 baseline tracks from two weeks prior to the training. From these tracks we have extracted a suite of kinematic and acoustic metrics and have aligned the tracks with relevant contextual variables (environmental, ship and sonar-related). We will present an overview of the analysis methods applied to these data thus far, with a focus on spatial analysis. The tracks have been analyzed in a spatially-explicit framework to determine whether the spatial distribution changed during sonar activities compared with baseline. Initial results indicate a difference in spatial distribution before and during the training activity, with fewer tracks on the range during the training.

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Incidental Take Authorizations: an Overview of the U.S. Marine Mammal Protection Act and Recent NOAA Streamlining Efforts

Topic
Policy developments and other stakeholders perspectives

Sound source
General (all sources)

Harrison, J. (1)

NOAA-NMFS is the lead U.S. agency responsible for minimizing the impacts of underwater noise on marine species and their habitat. The U.S. Marine Mammal Protection Act (MMPA) prohibits "take" of marine mammals, but includes provisions for the issuance of "incidental take authorizations (ITAs)" to allow for these impacts, provided certain findings are made. A brief overview of the process for obtaining ITAs will be presented. Further, recent improvements and efforts to increase efficiency and reduce burden on the public in this ITA process will be highlighted. Last, a very brief status update will be provided on the now-final Acoustic Technical Guidance, which compiles the best available science to identify acoustic thresholds above which auditory injury of marine mammals is expected to occur.

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Behavioral Response of Humpback Whales to US Navy Mid-Frequency Active Sonar

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field

Sound source
Sonar

Henderson, E. Elizabeth (1), Aschettino, Jessica (2), Deakos, Mark (2), Helble, Tyler (1), Alongi, Gabriela (3), Martin, Cameron (3), Martin, Steve (3)

Six humpback whales (*Megaptera novaeangliae*) were tagged with FastLoc GPS LIMPET-configured SPLASH tags off Kauai, HI near the Pacific Missile Range Facility in February, 2018, at the onset of a multi-vessel Submarine Commander's Course (SCC) training event. Five of the tags were still active when mid-frequency active sonar (MFAS) activities began. In addition, sixty-two seafloor mounted range hydrophones were recorded before, during, and after the training event. Ship movement patterns were recorded every second; received levels of MFAS from the ship will be estimated using propagation modeling. Therefore the movement behavior of the tagged whales can be analyzed for a response to both vessel movement and MFAS received levels (as estimated sound pressure levels and estimated cumulative exposure levels). The movement of seven humpback whales tagged off Kauai in March 2017 will be used as a baseline for response assessment. The presence of singing humpback whales in the acoustic data will also be examined, comparing acoustically-derived tracks recorded and localized on the range during the training event against those found throughout the humpback whale breeding season (December through June) since 2011. An initial examination of filtered satellite tracks indicates three whales moved rapidly across the channel from Kauai to Niihau near the time of the onset of MFAS, and none of the animals were present on or near the range for the duration of the training event.

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A need for standardization of evoked potential hearing test methods in odontocetes *(Poster)*

Topic
Hearing studies and other studies with captive animals

Sound source
General (all sources)

Houser, D.S. (1)

Auditory evoked potential (AEP) hearing tests are rapid and have become widely applied to trained, wild, and stranded odontocetes. The number of AEP audiograms is vastly greater than the number of behavioral audiograms available for odontocetes. However, AEP audiograms obtained to date have seen limited use in environmental compliance analyses. This has occurred for two reasons; differences in AEP hearing test methodologies can produce large differences in threshold estimates for the same species, or even the same individual, and the relationship between AEP and behavioral audiograms remains uncertain. Standardization of human hearing test methods enabled human hearing threshold data to be pooled and analyzed, even though it was collected by a diverse group of researchers and audiologists. In the same manner, standardization of AEP hearing test methods in odontocetes will reduce variability in AEP audiograms and contribute to making AEP audiograms more consistent across researchers and laboratories. Once consistency is achieved, differences between behavioral and AEP audiograms within the same individuals can be more systematically determined, thus making the AEP data more acceptable for use in compliance analyses. A national standard for AEP hearing test methods in toothed whales has been initiated in the United States. International adoption of the standard will further improve AEP threshold comparability by ensuring consistent application of AEP methodologies globally. Ultimately, standardization should contribute to the acceptance of AEP data for purposes of addressing ocean noise issues.

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Delphinid stress response to vibratory pile driving noise exposure

Topic
Stress response of animals exposed to sound

Sound source
General (all sources) /Pile Driving

Houser, D.S. (1), Branstetter, B.K. (1), Bowman, V. (1), Tormey, M. (1), Banks, P. (1), Champagne, C. (1), Finneran, J.J. (2), Jenkins, K. (2)

Anthropogenic noise exposure is speculated to cause stress in marine mammals. To determine the stress response to vibratory pile driving noise (VPN) exposure in a mid-frequency cetacean, five bottlenose dolphins performed an echolocation vigilance task with and without the presence of VPN. Sessions consisted of 30-minute pre-exposure, exposure, and post-exposure periods conducted in sequence. Exposures consisted of five different source levels of VPN (no-playback control, 110, 120, 130 and 140 dB re 1 μPa) played continuously during the exposure period. Five replicates of each test condition were performed. Voluntary blood samples were obtained within five minutes of the end of the pre-exposure and exposure periods for the 0, 120 and 140 dB conditions. Samples were processed for cortisol, aldosterone, epinephrine and norepinephrine. Three of five dolphins showed a significant decline in target detection performance on the first 140 dB re 1 μPa exposure, related to an almost complete cessation of echolocation activity. However, target detection performance returned to normal on subsequent exposures. No significant differences in hormone levels were observed between pre-exposure and exposure conditions for any hormone. Large individual variability in hormone levels was observed, suggesting possible differences in individual tolerances to the noise. However, neither cortisol nor aldosterone increased to levels observed under previously conducted acute stress tests wherein cortisol and aldosterone levels increased 2-3 times and up to 13 times, respectively, within 15-30 minutes of the beginning of the stress test. Results suggest rapid acclimation with possible noise-related performance reductions at the highest exposure level.

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Sperm whale behaviour responses to pulsed and continuous active sonar: a state based approach to estimate response thresholds and duration

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Isojunno, S (1), Wensveen P.J. (1,2), Lam F.-P. (3), Kvadsheim P.-H. (4), Von Benda-Beckmann A.M. (3), Martín López L.M. (1), Kleivane L (4), Siegal E. (1), Miller P.J.O. (1)

Recent advances in naval sonar technologies allow near continuous transmissions (Continuous Active Sonar, CAS), leading to more continuous illumination of targets and improved detection compared to traditional pulsed active sonar (PAS).
This raises imminent questions about the environmental impact of such future sonar systems. We conducted controlled exposure experiments of both CAS and PAS signals to contrast their impact on sperm whale behaviour in Northern Norwegian shelf waters. Sixteen individuals were outfitted with DTAGs and subjected to a no-sonar control approach and up to three 40-min sonar exposure sessions. We aimed to quantify response intensity (probability and duration of a response), measured in terms of changes in activity time budgets, and proxies for foraging effort (prey capture attempts) and foraging costs (locomotion effort), given the time budget.
An established state-based modelling was used to estimate the activity time budget in a Bayesian framework. Mixed models and model selection were used to quantitatively contrast candidate drivers for response intensity. Cumulative SEL (dB re 1μPa^{2}s over the session) best explained behaviour state switching to non-foraging active state, outperforming other metrics including instantaneous sound pressure level (SPL). We found no statistical evidence for different responses to CAS vs. PAS when the signals were received at equivalent SPL or SEL. Cessation of foraging was less likely during repeat sonar exposures and more likely when the whale had been exposed to pilot or killer whales previously in the tag deployment. Prey capture attempts and fluke stroke rates (min^{-1}) decreased during repeat sonar exposures.

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Temporary threshold shift and behavioral response in harbor porpoises due to exposure to 53-C sonar sounds, and TTS studies to derive a high-frequency cetacean weighting function

Topic
Hearing studies and other studies with captive animals & Controlled exposure experiments (CEE)

Sound source
Sonar

Kastelein, Ronald A. (1), Helder-Hoek, Lean (1), Cornelisse, Suzanne (1), Gransier, Robin (1), Van de Voorde, Shirley (1), de Winter, Simone (1), Janssen, Susan (1), and Ainslie, Michael (2)

Safety criteria for naval sonar sounds are needed to protect harbor porpoise hearing. Porpoises were exposed to AN/SQS-53C sonar playback sounds (3.5-4.1 kHz, without significant harmonics), at a sound pressure level (SPL) of 142 dB re 1 μPa, with a duty cycle of 96%. Behavioral hearing thresholds were determined before and after exposure to the sonar sound, to quantify temporary threshold shifts (TTSs) and hearing recovery. The SEL_{cum} required to induce 6 dB of TTS 4 min after exposure was between 175 and 180 dB re 1 μPa^2s.
Naval sonar signals may also affect the behavior of harbor porpoises. Therefore, porpoises were exposed to 30-minute playbacks of 53C sonar sounds at six SPLs and two duty cycles (2.7% and 96%). They did not respond to the sounds when the duty cycle was 2.7%. When the duty cycle was 96%, only one porpoise increased its respiration rate and moved away from the transducer, and only above a certain SPL. At the same SPL and duty cycle, the effect of 53C sonar sounds on harbor porpoise behavior was weaker than that of 1-2 kHz, 6-7 kHz and 25 kHz sonar signals.
So far, TTS susceptibility in harbor porpoises has been tested for sounds in the 1-7 kHz range. Therefore TTSs was quantified in porpoises that were exposed for one hour to continuous one-sixth octave noise bands centered at 16, 32 63 and 88.4 kHz. Once susceptibility has been quantified for the entire hearing range, weighting curves for high-frequency cetaceans can be generated.

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Effects of anthropogenic noise on spatial avoidance and foraging behavior in harbour porpoise *(Poster)*

Topic
Stress response of animals exposed to sound

Sound source
General (all sources)

Kok, A.C.M.(1), Engelberts, J.P.(1), Kastelein, R.A.(2), Helder-Hoek, L.(2), Van de Voorde, S.(2), Visser, F.(1,3,4) & Slabbekoorn, H.(1)

The current rise in underwater sound levels in the oceans is leading to disturbance of marine life. It is thought that one of the main impacts of sound exposure is the alteration of foraging behaviour of marine species, for example by deterring animals from a prey location or by distracting them while trying to catch prey. So far, only limited knowledge on both mechanisms in the same species is available. The harbour porpoise (*Phocoena phocoena*) is a relatively small marine mammal that could suffer quickly from a decrease in foraging success. To test the effect of sound on their foraging efficiency, we tested whether experimentally elevated sound levels would deter two captive harbour porpoises from a noisy pool (Experiment 1) and reduce their prey-search performance in a noisy pool (Experiment 2). Furthermore, we tested whether two sound characteristics (amplitude and temporal structure) influenced the effect of the sound. Both individuals avoided the pool with elevated sound levels, but they did not show a change in search time for prey in the prey-search task. The combination of temporal structure and SPL caused variable response patterns, leading to spatial avoidance with distinct dose-response patterns. Hence, temporal structure of sound is another important factor, besides SPL, that has to be taken into account when predicting effects of sound exposure on animals.

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Overview of the U.S. Navy's Living Marine Resources (LMR) Program

Topic
Policy developments and other stakeholders perspectives, Hearing studies and other studies with captive animals, TTS-effects and physiology, Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field, Tag development, Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking, Active acoustics

Sound source
Sonar, Explosions

Kumar, Anu (1); Shoemaker, Mandy (1); Kitchen, Danielle (2)

In its ongoing effort to reduce potential impacts to marine mammals while meeting at-sea training and testing requirements, the U.S. Navy supports both basic and applied research to improve the understanding of marine mammals in regards to occurrence, exposure, response, and consequences. The Living Marine Resources (LMR) program is responsible for funding applied research, and works to address the Navy's key research needs and transition the results and technologies for use within the Navy's at-sea environmental compliance and permitting processes, with the goals of improving marine species impact analysis, mitigation measures, and monitoring capabilities. The program's funding priorities includes:

1. Data to Support Risk Threshold Criteria
2. Data Processing and Analysis Tools
3. Monitoring Technology Demonstrations
4. Standards and Metrics
5. Emergent Topics

The LMR program is currently heavily invested in data to support risk threshold criteria, passive acoustic monitoring technologies, and automated methods of acoustic data analysis. These methods are seen as an integral component of the Navy's current monitoring plan. We present an overview of the LMR program, how we fit and work with the Office of Naval Research's marine mammal program and the U.S. Navy's marine species monitoring program and LMR's current investments related to marine mammal research. The LMR program is sponsored by the Chief of Naval Operations (CNO) Energy and Environmental Readiness Division (N45). An advisory committee, comprised of representatives within the US Navy, solicits input from all commands to establish the annual research needs topics and assist in evaluating and selecting projects for funding.

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The Sea mammals and Sonar Safety (3S) project – behavioral responses to naval sonar in six species of marine mammals

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Kvadsheim, P.H. (1), Miller P..JO. (2), Lam FP (3), Isojunno S. (2), Wensveen P.J. (2,4), Sivle L.D. (5), Curé C (6), Tyack P.L. (2), Kleivane L. (7), von Benda-Beckmann S. (3), Hansen R.R. (7), Benti B. (2,6), Visser F. (8)

The 3S project started in 2006 and is now in its third phase. We have deployed 162 acoustic and motion sensor tags to six species of cetaceans and conducted 91 sonar exposure and 97 control experiments. Avoidance responses and changes in dive behavior, feeding behavior, vocal behavior, social interaction or lack of such in response to naval sonar have been studied in killer whales, pilot whales, sperm whales, bottlenose whales, minke whales and humpback whales. Specific questions like species differences in sensitivity, frequency specificity in responses, effectiveness of ramp up, habituation, and biological relevance of responses have been addressed. We are using a dose escalation design to derive dose response functions for different species and types of responses. Probability of response at different received levels can be used to estimate the affected area around different operational sources and ultimately the numbers of animals disturbed. However, recent studies indicate that the distance to the source might modulate the dose response function. Also, a trend in active sonar technology is that the duty cycle of the sonar systems are increasing, and modern active sonars can transmit almost continuously. In the current third phase of the 3S project we are investigating how the distance to the source affect behavioral responses, and if exposure to continuous-active-sonar (CAS) signals lead to different types or severity of behavioral responses than exposure to traditional pulsed-active-sonar (PAS) signals. This presentation will give an overview of the 3S project. Other presentations will detail specific aspects of the results.

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Soundscapes, Passive Acoustic Monitoring (PAM), and Ecosystem Level Effects: A Discussion of Some of the Temporal Issues needed to Bridge the Analysis Gap
(Poster)

Topic
Soundscapes, Passive Acoustic Monitoring (PAM), and Ecosystem Level Effects: A Discussion of Some of the Temporal Issues needed to Bridge the Analysis Gap

Sound source
General (all sources)

Labak, Stanley J., Marine Acoustician

Currently in the underwater sound community, there are numerous efforts being made to collect soundscapes and ambient noise data, and to develop technics and metrics to analyze this data. Much of that effort is directed at reliably identify and measure individual sound sources in the geophony (wind, wave, rain and ice), biophony (individual species calls or choruses), and anthrophony (ship, seismic, sonar, explosives). However, being able to identify these sources in a set of acoustic data does not easily translate into a measurement of the possible impact of those acoustic sources on the environment in which they were recorded. Also, these datasets may not be sufficient, even with future reprocessing, to assess the impact of anthropogenic activities. For example: are they adequate to characterize the multipath or reverberation environment; can the spatial extent of the impulsive nature of some signals be quantified; or are the measurements sufficient to observe an increase in ambient noise due to multiple of persistent sources?

The spectral analysis techniques used in PAM and soundscape analyses are well developed, but temporal approaches or criteria seem to be underrepresented in most Acoustic Variability Indices (AVI) analyses. It is the intent of this paper to examine these temporal measurements and to assess where it may be advantageous to use them. Due to the general nature of the typical ambient noise or soundscape acoustic measurement, that is, that frequently either the receiver or the sources are moving, this temporal discussion will also need to include a spatial component.

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Towards a science-based approach to mitigate impacts from marine seismic surveys

Topic
Policy developments and other stakeholders perspectives, Dissemination of Knowledge

Sound source
Seismic (airguns)

Lamont, Christine (1), Staaterman, Erica (2), Lewandowski, Jill (2), Carter, Tim (1)

Over the last 50 years, marine seismic surveys have been used widely across the world's oceans to search for oil and gas deposits. There are multiple regulatory jurisdictions and a variety of regulatory approaches that apply to the areas where these surveys are conducted.

We conducted a review of the existing acoustic impact mitigation measures for cetaceans and the scientific research supporting the design and use of these measures. The review targeted the 12 countries that are members of the International Offshore Petroleum Environment Regulators (IOPER) Marine Sound Working Group. Some interesting similarities and differences emerged in terms of the measures used by each regulatory regime, the level to which those measures are required or recommended, and how they are applied. There was also some interesting variation in terms of the scientific basis for the selection, design and implementation of those mitigation measures.

Inconsistencies in mitigations that are required or recommended in different jurisdictions may result in additional burden for exploration companies that work across jurisdictions. These companies are challenged to demonstrate that impacts to cetaceans will be appropriately mitigated and regulators are spending considerable time assessing the suitability of these proposals, yet stakeholders have low confidence that sensitive species will be protected.

Coordinated and collaborative scientific research into the effectiveness of acoustic mitigation measures could result in the development of a common set of international good practice acoustic mitigation measures, and improved social license to operate and regulate.

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Getting off the Conflict Carousel: The Case Study of Ocean Noise and Marine Mammals *(Poster)*

Topic
Policy developments and other stakeholders perspectives**,** Dissemination of Knowledge

Sound source
All oil and gas sources with emphasis on airguns

Lewandowski, Jill, Ph.D.

Like many major environmental issues of our time, ocean noise is characterized by high levels of scientific uncertainty, diversified values across many stakeholders, political and regulatory complexities and a continually evolving ecological and social environment. Standard approaches to decision-making are generally not designed to meet the complexity of the issue. What results is continuing controversy, failed management decisions, litigation and an increasing frustration by all parties on why a better solution cannot be found. Ultimately, progress on this issue will fail unless all parties better understand what is driving the conflict, the actions of those involved and what is needed to move people and groups from established positions to more effective collaborations.

This presentation will provide final results from a review of 230 documents and the conduct of 58 semi-structured, in-depth interviews with stakeholders engaged on this issue. These interview data are being combined with interview data collected from collaborative action experts to develop a 'non-standard' collaborative action framework specifically designed to address the ocean noise issue. High level results will be provided for responses related to naval sonar, commercial shipping, renewable energy and oil and gas. Further, new analyses that dig deeper into oil and gas issues will also be presented.

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Regulatory challenges: looking beyond our backyard

Topic
Policy developments and other stakeholders perspectives**,** Dissemination of Knowledge

Sound source
Air guns, pile driving

Lewandowski, Jill, Ph.D.

The U.S. Bureau of Ocean Energy Management is responsible for stewardship of U.S. offshore energy and mineral resources, as well as protecting the environment that the development of those resources may impact. For more than 30 years, this mandate has included studying, regulating and mitigating against the effects of industry-produced noise on marine life (https://www.boem.gov/Fact-Sheet-on-Sound-Studies/).

Recognizing the far-reaching aspects of this complex environmental issue, and the international activities of the industries we regulate, BOEM also works collaboratively with regulators internationally to better understand, share information and manage marine noise issues. One example includes BOEM's leadership role in the International Offshore Petroleum Environmental Regulators (IOPER) Marine Sound Working Group (http://www.ioper.org).

This presentation will take place in two parts, moving from a U.S. perspective to an international focus. The first part will broadly explain actions BOEM has taken to better understand and lessen the impacts of industry-produced noise on marine life. It will also cover perceived regulatory challenges from a U.S. perspective. The presentation will then describe the challenges in managing this issue across geopolitical boundaries and will end by giving a synopsis of the 2018 September 9th IOPER Regulators Forum on the regulation and management of impulsive noise sources.

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Automatic Localization of Sperm Whales and Sei Whales during Marine Seismic Survey *(Poster)*

Topic
Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking

Sound source
Seismic (air guns)

L'Her, Christophe (1), Coatelan, Stéphane (1), Vallez, Simon (1)

This article shall demonstrate the performances and opportunities provided by a Passive Acoustic Monitoring (PAM) system integrated within seismic streamers.

The cetacean detection domain is broad because of the variety of the vocalizations possible and complex because the actual truth is rarely known. We focus on two case studies: the automatic localization of Sperm whales and Sei whales.

The localization of sperm whales is challenging as sperm whales vocalize while diving hundreds of meters, which makes it difficult to accurately localize in the horizontal plane. We present here the method used to localize in 3D and present some results.

Then we assess the capability of QuietSea to detect and localize Sei whales which produce downsweep calls that overlap with the seismic bandwidth. A method checking periodically that calls are not hidden by the background noise is presented.

Although Sercel, with the support and commitment of CGG, has accumulated data during several years aboard several seismic vessels; this paper specifically provides analysis of mammal monitoring in the Gulf of Mexico and offshore Mauritania, where the PAM system was operated as a primary system.

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Baleen whales acoustically derived behaviors with potential responses to US Navy sonar training

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Martin, Stephen W. (1), Martin, Cameron (1), Matsuyama, Brian (1), Alongi, Gabriela (1), Henderson, E. Elizabeth (2), Helble, Tyler (2) and Ierley, Glenn (3)

An opportunistic behavioral response study is being performed utilizing passive acoustic data (PAM) collected at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. PAM data has been collected at PMRF for over a decade both for baseline periods and more recently during periods of U.S. Navy mid-frequency active sonar (MFAS) training. The Office of Naval Research's Behavioral Response Evaluations Employing Robust Baselines (BREVE) project is utilizing this data to establish acoustically derived behaviors for baleen whale species and adapting methods previously developed for controlled exposure experiments for behavioral responses to sonar. Baleen whale species currently being detected, localized and tracked include minke, Bryde's, humpback, fin, and sei, whales. A companion presentation (Harris et al.) describes results to date for 60 minke whale tracks in February 2014 with an emphasis on spatial analysis. Given that no tags are on the whales, their MFAS exposures are estimated using propagation modeling and cumulating the sound exposure level (cSEL) from all sources present over the duration of individual whale tracks (ranging from a few to tens of hours). Whales' potential behavioral responses to MFAS include cessation of calling, changes in movement and spatial patterns, and changes in call characteristics (e.g. call types and call intervals). This presentation provides an overview of the automated methods and metrics currently being utilized with examples for multiple baleen whale species acoustic encounters including some with potential vocal behavioral responses to MFAS (cessation of calling and longer call intervals).

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Geophysical surveys – some challenges when advising on risk assessment and mitigation *(Poster)*

Topic
Policy Developments and other stakeholders perspectives

Sound source
Seismic (airguns) and High resolution geophysical surveys

Mendes, Sonia (1), Canning, Sarah (1), Box, Tetrienne (1), Marubini, Francesca (2)

In the UK, statutory nature conservation agencies such as JNCC advise on geophysical survey permits and work with the Oil and Gas regulator as well as industry to improve standards of risk assessment and mitigation. Over the last couple of decades, understanding of the characteristics of noise resulting from these surveys as well as of the effects on marine mammals has much improved, however challenges remain as to how to assess the risk of hearing damage and disturbance and how to mitigate effectively. Geophysical surveys are widespread with airgun surveys having been responsible for the majority of pulsed noise in UK waters, followed by sub-bottom profiler surveys. Some of the challenges faced when assessing risk will be discussed, including the implications of the NOAA thresholds, the effect of ramp up, estimating cumulative exposure and how to best estimate the risk of disturbance. Whereas there have been a few studies on the effects of seismic noise on marine mammals and some level of inference can be made from noise modelling and measurements, comparatively little is known about the sound propagation of the different sub-bottom profilers and how animals might respond to these sources. Given their increased use by offshore industries there is some urgency in gaining further data. The challenges faced when assessing the risks arising from geophysical surveys translate into challenges regarding mitigation and licensing, particularly when trying to balance precaution with proportionality.

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Incorporating Annual Variability of Source Level and Distribution in Large Scale Density Estimation of Fin Whales from a Sparse Array

Topic
Population Estimation

Sound source
N/A

Miksis-Olds, Jennifer L. (1), Harris, Danielle (2), Thomas, Len (2)

Effective management and mitigation of marine mammals in response to potentially negative interactions with human activity requires knowledge of how many animals are present in an area during a specific time period. Many marine mammal species are relatively hard to sight, making standard visual methods of density estimation difficult and expensive; however density estimation from passive acoustic monitoring data is an attractive, cost-effective alternative.
A particularly efficient passive acoustic monitoring design is a "sparse array", where sensors are distributed evenly over a large area of interest. A consequence of this design is that each vocalization cannot be heard at multiple sensor locations, restricting the choice of density estimation methods. While previous sparse array methods represent an important step forward in making density estimation methods more generally applicable at reasonable cost, they are only applicable to small ocean areas, and/or require unrealistic assumptions about animal distribution around the sensors. This effort utilized sparse array data from the Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System to develop and implement a new method for estimating fin whale density over large spatial scales and is designed to cope with spatial variation in animal density. Fin whale densities around Wake Island are presented; decadal variability in whale source level and distribution was incorporated to improve accuracy and precision of the annual estimates. The method developed for the low frequency vocalizations of fin whales is directly applicable to other species and frequency ranges using sparse arrays of fixed or remotely deployed PAM systems.

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The underwater soundscape of fear: relating experimental responses of cetaceans to navy sonar and predator sound presentations

Topic

Behaviour response studies (BRS) in the field and Population-level and ecosystem level effects (PCOD and other)

Sound source

Sonar and predators sounds of MM-feeding killer whales

Miller, P.J.O. (1), Isojunno S. (1), Siegal E. (1), Lam F.P.A. (2), Kvadsheim P.H. (3), Curé C. (4)

The risk-disturbance hypothesis proposes that anthropogenic sounds may be perceived by animals as a threat similar to predator presence, driving individuals to trade fitness-enhancing behaviors such as foraging for perceived safety. In this study, we quantify if and how cessation-of-feeding responses to predator sound presentations (playback of mammal-feeding killer whale sounds) of four cetacean species (long-finned pilot, humpback, sperm and bottlenose whales) correspond to how individuals responded to 1-2 kHz naval sonar in the 3S behavioral response study. Using species-specific movement and/or echolocation click production parameters recorded on suction-cup attached Dtags, we distinguished dive types containing intense-active foraging vs non-foraging and exploratory foraging behavior. Proportion of time spent in the different behavioral states was modeled in generalized estimating equations (GEE) with individual as a panel variable. Within records of all four species, we found reductions in intense-active foraging behavior during predator sound presentations and 1-2 kHz sonar signals, compared to pre-exposure baseline periods. The bottlenose whale was the most responsive species, with complete and extended cessation of foraging during both exposure types, followed by humpback whales which strongly reduced foraging activity during exposure to both signal types. Sperm and long-finned pilot whales decreased foraging time to a lesser extent to both signal types. The apparent correspondence between reductions in foraging time observed during predator presentations and experimental transmission of 1-2 kHz naval sonar sounds, across different cetacean species, indicates that the risk of disturbance from anthropogenic sounds may be a predictable function of a species' underlying vulnerability to predation.

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Technical advances in inner ear analysis to assess potential hearing loss and first prediction of cochlear frequency map for harbor porpoise

Topic
TTS-effects and physiology

Sound source
General (all sources)

Morell, Maria (1), IJsseldijk, Lonneke L. (2), Adrien Caplot (1)

We developed a protocol to analyze the inner ears from stranded harbor porpoises to study whether the animals have suffered a permanent hearing loss. We combine scanning electron microscopy and immunofluorescence to detect potential lesions in the neurosensory epithelium of the inner ear. In addition, we can distinguish between newly formed lesions (potentially linked to the stranding) from chronic ones. Here, we also present the first prediction of the cochlear frequency map, or distribution of frequencies along the cochlear spiral, for harbor porpoise.
The importance of having these maps relies in the possibility to extrapolate the acoustic characteristics of a source if we find lesions associated to noise exposure. In mammals, the base of the cochlea encodes for high frequency sounds, while low frequencies are detected in the apex. Morphometric variation occurs in cells of the organ of Corti (the hearing organ) along the spiral. These changes in cell shape and spacing are related to the frequencies encoded at different locations, as shown in the guinea pig. Cochlear frequency maps for harbor porpoise have been predicted from traditional and geometric morphometric measurements of the organ of Corti from 10 locations of the cochlear spiral. The same procedure was previously followed with mustached bat and rat inner ears to train machine learning techniques to predict the maps for other cetacean species, such as beluga.
The ability to combine morphological and auditory data will be crucial to validate predictions of cochlear frequency maps for harbour porpoise based on morphological features.

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Estimating Cuvier's and Blainville's beaked whales' risk of behavioral disturbance from exposure to mid-frequency active sonar

Topic
Stress response of animals exposed to sound, Population-level and ecosystem level effects (PCOD and other), Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking, Population estimation

Sound source
Sonar

Moretti, David, Jones, Ben, DiMarzio, Nancy, Jarvis, Susan, Watwood, Stephanie, Morrissey, Ronald, Dolan, Karin (1), Thomas, Len, Harwood, John (2)

Strandings of Blainville's and Cuvier's beaked whales have been associated with the use of mid-frequency active sonar (MFAS). Both species are found on U.S. Navy ranges, where they are repeatedly exposed to MFAS, though no mass stranding have been reported at these facilities. However, disruption of foraging dives has been observed in both directed and opportunistic studies. To understand the effect of such disruption, detections of vocalizations by Blainville's beaked whales at the Atlantic Undersea Test and Evaluation Center (AUTEC) and by Cuvier's beaked whales at the Southern California Offshore Range (SCORE) on the hydrophone arrays at the sites have been analyzed to provide time series of estimates of abundance. The received level of MFAS sound at each vocalizing group of beaked whales has also been estimated and used to fit a risk function that relates the probability of foraging dive disruption to received level. These datasets are also being used in conjunction with a simple bioenergetics model to investigate the potential population level effect of repeated disruption.

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U.S. Navy Environmental Compliance for At-Sea Training and Testing

Topic
Policy Developments

Sound source
General (all sources)

Nissen, Jene (1), Jenkins, Keith (2), Henderson, Elizabeth (2)

Conducting safe and effective training at sea is one of the most important missions the U.S. Navy performs during peacetime. The U.S. Navy is also committed to ensuring environmental stewardship and proactively coordinates with regulatory agencies to protect the marine environment. While we recognize that training and testing activities have the potential to impact the environment, the Navy employs every means available, without jeopardizing the safety of Sailors or impacting our military readiness mission, to analyze and mitigate any potential environmental effects. Prior to conducting these activities, the Navy consults extensively with environmental regulators to ensure the best available science is used to produce analyses that can withstand litigative and scientific scrutiny. In order to analyze the effects of sound or explosive energy introduced into the environment by U.S. Navy activities, criteria and thresholds are developed to predict behavioral response, hearing threshold shifts, and injury. Best available science is used to synthesize these criteria which are vetted through the scientific community and regulators. These criteria are the cornerstone of the analysis of impacts to marine mammals from sound producing activities. This presentation will present U.S. Fleet Forces Command's at-sea environmental compliance program and process in the Atlantic Ocean with respect to the U.S. Marine Mammal Protection Act and Endangered Species Act. It will also discuss how the best available science that the U.S. Navy uses to assess potential impacts and mitigate the impact of their activities.

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Understanding the population consequences of disturbance – the PCoD+ project

Topic
Population-level and ecosystem level effects (PCOD and other)

Sound source
General (all sources)

Pirotta, Enrico (1), Booth, Cormac (2), Costa, Daniel (3), Harris, Catriona (4), Joy, Ruth (2), New, Leslie (1), Schick, Robert (5), Schwarz, Lisa (3), Simmons, Samantha (6), Thomas, Len (4), Todd, Charlotte (2), Tyack, Peter (7), Weise, Michael (8), Wilson, Lindsay (2), Harwood, John (2).

The PCoD+ project (running 2016-2019), which is funded by the US Office of Naval Research, aims to develop widely applicable models of the population consequences of disturbance (PCoD). It has five research tasks:

- The development of methods for assessing aggregate exposure (i.e. the number of times that an individual is likely to be exposed to disturbance in a particular time interval);
- The development of a decision framework that can be used to prioritize the development of PCoD models for populations that are likely to be most affected by disturbance, and to identify the most appropriate model structure given the available data;
- The creation of a set of detailed benchmark PCoD models that can be used to to assess the data requirements and sensitivities of simpler models, and to inform expert elicitations;
- The development of a standard protocol for expert elicitation in a PCoD context; and
- The identification of priorities for monitoring the early warning signs of PCoD in marine mammal populations.

We will review progress on each of these tasks.

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Hazard zones for potential auditory damage – Estimated cumulative effects of pile driving for harbour porpoises in the German North Sea *(Poster)*

Topic
TTS-effects and physiology

Sound source
Pile driving

Schaffeld, Tobias (1), Ruser, Andreas (1), Schnitzler, Joseph (1), Wölfing, Benno (1), Baltzer, Johannes (1), Siebert, Ursula (1)

Impulsive sound has the potential to evoke temporary threshold shifts (TTS) in harbour porpoise (*Phocoena phocoena*) hearing, which is regarded as an injury and therefore prohibited by law throughout Europe. Anthropogenic produced impulsive sounds at very high source levels arise from pile driving of offshore wind turbine foundations. Sound energy levels of single pile driving events are limited in Germany to a maximum of 160 dB re 1 µPa²s at a distance of 750 m to prevent a potential TTS in harbour porpoises. Recent studies revealed the potential to suffer from a TTS when exposed to multiple impulsive sounds well below the permitted limit of 160 dB re 1 µPa²s. A TTS onset from multiple pile driving events was estimated at a cumulative SEL of 175 dB re 1 µPa²s. Effects of multiple pile driving events were evaluated against recent TTS thresholds for these animals by means of simulating a potential flight response of harbour porpoises. Underwater recordings of pile driving events around a German offshore wind farm, transmission loss, pulse interval and estimated swim speed of harbour porpoises were used to calculate received levels during simulated flight responses. Depending on swim speed, potential hazard zones with a radius between 2000 and 4600 m have been determined, where the TTS onset of 175 dB re 1 µPa²s could be exceeded if harbour porpoises start to flight at the first pile driving event. Extended pulse intervals proved to be an effective tool to reduce the simulated hazard zones.

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Impact of vibroseismic underwater sound on the behaviour of baleen whales

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field

Sound source
Marine vibrator

Schnitzler, Joseph (1), Rasmussen, Marianne Helene (2), Lucke, Klaus (3), Akamatsu, Tomonari (4), Wahlberg, Magnus (5), Baltzer, Johannes (1), Stepien, Emilie Nicoline (5), Villum, Mikkel (6), Ruser, Andreas (1), Siebert, Ursula (1)

The objective of the project is to study effects of marine vibrator sounds on the behaviour of baleen whales. Marine vibrators (MV) may work as an alternative for seismic airguns with a high potential to reduce hearing impairments and disturbance effects for marine mammals. The signals emitted by the MV have considerable lower peak pressure levels and reduced energy above 100 Hz. Furthermore, the ability of MVs to spread the energy output over time as continuous frequency-modulated (FM) or pseudo-random noise sweep makes it a promising alternative technology to airguns. However, there are concerns regarding the masking potential for low frequency specialists. There is limited knowledge regarding masking and type of signal produced by MV. It is currently perceived that FM sweeps will have the least amount of impact on these species due to limited energy in each frequency band that are therefore used in our project. In a first field study 2017, the baleen whales were tagged using acoustic tags (AUSOMS). Low frequency sounds similar to those from MVs were generated via an underwater loud speaker (Argotec, SS-2). The tags record the received sound level at the animal, vocalisation, depth as well as fine scale movements and environmental parameters. By using these devices, we are able to correlate swim direction, swim speed, dive profile, behavioural pattern and vocalisation with received sound levels before, during and after sound exposure. Simultaneously, passive acoustic monitoring with a hydrophone array and visual observations from several platforms were conducted to record any behavioural changes.

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Spatial, spectral and temporal distribution of sound for selected sound sources in the Dutch North Sea

Topic
Technical/tool developments

Sound source
General (all sources)

Sertlek, Hüseyin Özkan (1,2), Slabbekoorn, Hans (1), ten Cate, Carel (1), Ainslie, Michael A. (3)

Effective measures for protecting and preserving the marine environment require an understanding of the potential impact of anthropogenic sound on marine life. In this work, we explored the spatial, spectral and temporal distribution of four selected sound sources in the Dutch North Sea (wind, shipping, explosions and seismic airguns). First, we calculated annually averaged sound maps for the selected sound sources in the Dutch North Sea. Then, we ranked these selected sound sources according to annually averaged total acoustic energy in the Dutch North Sea over a two-year time period in various frequency bands between 100 Hz and 100 kHz. The sounds map can be used to zoom into species-specific exposure probabilities through weighted sound mapping based on typical swimming depths and hearing ranges. These applications reveal the flexibility and scope of sound mapping and should become a practical tool for biologists, conservationists, policy makers and legislators.

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Polar Winter Research Expeditions to the Singer-songwriters of the Arctic sea ice: Spitsbergen's remnant Bowhead whale population.

Topic
Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking and Population estimation

Sound source
Seismic (air guns)

Sips, Herman J.J.

Bowhead whales are particular vocal animals, bound to the Arctic sea ice. With the melting of the ice, the species not only faces the ultimate reduction of its critical habitat, but also the acoustical interference of increased shipping and seismic exploration. Despite their conspicuous role as the only Arctic resident baleen whale, Bowhead whales are relatively unknown to science due to the inaccessibility of the habitat, especially during the polar winter. Considering the rapidly changing Arctic environment, targeted research on Bowhead whales to assess population characteristics and its potential drivers is of urgent importance.
Recordings from a fixed hydrophone within the drift ice zone of the Fram Strait between Spitsbergen and Greenland revealed Bowhead whales producing a great diversity of complex songs during the midst of Arctic winters. These songs are far more varied and elaborate than Bowhead whale sounds known from other Arctic areas, presumably representing a kind of singer-songwriter courtship ritual, and thus a mating area. Yet, mating areas of Bowhead whales have never been described before.
The *Icewhale Foundation* will organize a series of Arctic winter expeditions to assess the composition and wintering distribution of the Spitsbergen's Bowhead whale population in relation to the drift ice system. Special emphasis will be placed on the passive acoustical distinguishability and the tracking of individual whales. Supported by Dutch institutes we are currently developing a specific 'silent' drift ice vessel to gain access to the polar winter habitat of Bowhead whales and to investigate the area with appropriate acoustical methodology.

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A Risk Assessment Framework to Evaluate the Potential Relative Effects of Noise on Marine Mammals *(Poster)*

Topic
Policy developments and other stakeholders perspectives.

Sound source
General (all sources)

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

Many traditional regulatory approaches evaluate how human noise may negatively affect marine mammals using broad average values to characterize animal distribution and simple, threshold-based noise exposure criteria. It is increasingly clear that such approaches fail to capture the complex reality of real exposure scenarios and outcome probabilities. Spatial and temporal variability in animal distribution strongly affects interaction with and exposure to noise sources. Spectral interactions among animal hearing and noise sources and contextual aspects of exposure (*e.g.*, relative proximity, animal behavioral state) can be as or more important than received level, particularly for behavioral responses. Evaluations of potential effects on individual life functions affecting fitness (*e.g.*, foraging, survival, reproduction) are needed within the context of populations; an area of considerable ongoing modeling effort (*e.g.*, PCOD). Recognizing the need to integrate spatial-temporal-spectral contexts of noise exposure, we developed a novel, transparent, and easily-applicable risk assessment process with quantitative methods where possible, and subjective evaluation where necessary. The resulting framework integrates biologically-based, risk assessment methods with some existing approaches for predicting potential injury and behavior, in order to ensure regulatory consistency. We present a paradigm that considers relative 'vulnerability' (potential species- and context-dependent susceptibility) and exposure 'severity' (relative exposure intensity within the context of a population) as the two primary dimensions of overall risk. The resulting analytical framework is modular and scalable, allowing application at variable resolutions, from discrete noise activities on relatively fine spatial and temporal scales to multiple activities (aggregate exposures) over larger regions, seasons, and years.

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Atlantic Behavioral Response Study: Experimental Design, Analytical Methods, and Preliminary Results

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field

Sound source
Sonar

Southall, B.L[1,2], Baird, R.W.[3], Bowers, M.[2], Cioffi, W.R.[4], Foley, H.[4], Friedlaender, A.[1,2], Harris, C.[5], Joseph, J.[6], Margolina, T.[6], Nowacek, D.P.[4], Quick, N.[4], Read, A.[4], Schick, R.[4], Shearer, J.[4], Swaim, Z.[4], Waples, D.[4], Webster, D.L.[3], Wisse, J.[4]

The Atlantic Behavioral Response Study (BRS) is quantifying the behavioral responses of cetaceans to military mid-frequency (~3-4 kHz) active sonar (MFAS) systems. Our multi-institutional collaboration leverages extensive baseline monitoring of Cuvier's beaked whales (*Ziphius cavirostris*) and short-finned pilot whales (*Globicephala macrorhynchus*) off Cape Hatteras, NC and employs experimental methods developed in previous BRS work. Our research approach is facilitated by a high density of Cuvier's beaked whales in this region. The experimental design is a before-during-after controlled exposure experiment (CEE), but there are several unique aspects of the study. Notably, we combine the use of short-term, high-resolution archival tags and longer-term, coarser resolution satellite-linked tags to examine responses at different temporal and spatial scales. Furthermore, the study occurs in an area outside an active military range, where MFAS training exercises occur relatively infrequently. Our approach is designed to test for specific responses in: horizontal avoidance; foraging behavior; and social affiliation. In our first field season (2017) we deployed satellite tags on 14 beaked and 12 pilot whales as well as high resolution archival tags on individual beaked and pilot whales. We also conducted 21 unique CEE sequences on tagged whales, with both simulated and operational MFAS. Preliminary analyses suggest some short-term behavioral responses (horizontal avoidance, cessation of feeding) from some, but not all, individuals. We found no large-scale abandonment of habitat or long-term cessation of feeding. Our subsequent field efforts will increase sample size and address contextual variables relevant to response probability, including: source-animal range, received level, and behavioral state.

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Passive acoustic density estimation: methods evaluation and survey design

Topic
Passive acoustic monitoring (PAM) and Detection, classification and localization (DCL) and tracking

Sound source
General (all sources)

Thomas, Len (1), Marques, Tiago (1), Harris, Danielle (1), Oedekoven, Cornelia (1), Marshall, Laura (1), Tyack, Peter (1), Johnson, Mark (1), Gillespie, Douglas (1), Kim, Katherine (2), Blackwell, Susanna (2), Conrad, Alexander (2), Thode, Aaron (3), Phillips, Goldie (3, 4), Nowacek, Douglas (4), Wells, Randall (5), Moretti, David (6), Booth, Cormac (7), Joy, Ruth (7), Wood, Jason (7), Verfuss, Ursula (7)

We report on four projects advancing our knowledge on estimation of marine mammal population density from fixed passive acoustic sensors.
First is an evaluation of multiple methods for estimating call density using detections of bowhead whale calls made on multiple arrays of Directional Autonomous Seafloor Acoustic Recorders (DASARs) over the Arctic continental shelf. We compare three methods (direct census, point transect and spatially explicit capture recapture (SECR)) on both automated and manually-derived detection data.
Second is also methods evaluation, using a custom-designed study on a long-term resident population of bottlenose dolphins in part of Sarasota Bay, Florida. Several variants of point transect, mark recapture and SECR methods are compared, using detections of dolphin whistles. This is the first study where density estimation methods are field tested against known true density.
Third is an ongoing demonstration of survey design and field methods for cost-effective density estimation of beaked and fin whales, ongoing in southern California. A dispersed array of sensors is deployed through the study area and used to estimate fin whale density using SECR; a subset of sensors are capable of ranging and are used to estimate effective detection area for Cuvier's beaked whales, thereby providing the link to their density estimation.
Fourth is a software simulation tool that allows exploration of power to monitor population trends from designs such as those described above.
We thank JIP E&P Sound and Marine Life, Duke University & Sarasota Dolphin Research Program, US Navy LMR program and JIP respectively for support.

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Long-range, short-term responses of harbour porpoises to a 3D seismic survey in the central North Sea *(Poster)*

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field

Sound source
Seismic (air guns)

Tougaard, Jakob (1), Sarnocinska, Joanna (1), Beest, Floris F.V. (1), Balle, Jeppe (1), Teilmann, Jonas (1)

Echolocation activity of harbour porpoises were monitored by passive acoustic monitoring (C-PODs) at nine stations in the North Sea during a 3D seismic survey. The survey lasted 103 days during summer and autumn 2016 and covered approximately 3,600 km of transect lines with a 3570 in^3 airgun array. Porpoise clicks were detected in large quantities throughout the survey period. However, there was a gradual, but pronounced decrease in detections whenever the source vessel was closer than 8-12 km from the recording stations, indicating a distinct, short-term reaction of porpoises to the seismic source. It is unknown whether this was caused by porpoises fleeing from the sound, a cessation of vocalisation, or a combination. A parallel decrease in presence of short interpulse-interval clicks (buzzes) indicated reduced feeding by porpoises close to the airgun array.
Airgun pulses were recorded at six stations (Wildlife Acoustics SM2M/SM3M) and confirmed that most energy was present at very low frequencies (peak frequency below 500 Hz), but also presence of energy above ambient noise at higher frequencies, more audible to porpoises. Mean backcalculated source level was 230 dB re. 1 μPa^2s (unweighted), comparable to source levels from pile driving of large-diameter steel monopiles. Maximum reaction distance, however, was considerably smaller than what has been seen for unmitigated pile driving, consistent with the lower peak frequency and duty cycle of the airgun pulses. Duration of reactions were also shorter than seen for pile driving, consistent with smaller overall exposure to individual porpoises due to the moving source.

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Baleen whales divulge a physiological response to 150 years of global anthropogenic stressors

Topic
Effects of sound on marine life/ Stress response of animals exposed to sound

Sound source
N/A

Trumble, S.J. (1) Norman, S. A. (2) and Usenko, S. (3)

The impact of global industrialization over the past two centuries has resulted in unprecedented changes to the marine environment. For the largest animals to have ever occupy this planet, baleen whales, assessing possible interactions with past anthropogenic pressures had remained a mystery. Recent techniques using whale earplugs have combined age estimates with cortisol measurements to reconstruct lifetime stress profiles, providing an unprecedented opportunity to assess spatial and temporal stress/stressor relationships. Here we show a strong relationship (r^2=0.79) between whale cortisol levels from earplugs spanning 147 years (c.1869-2016) with 20th century whaling counts (proxy for whaling effort) in the Northern Hemisphere. While whaling itself directly impacts whales, we suggest indirect effects include increased ship traffic and associated increase in sound. Interestingly, from 1939-1945 (WWII) the cortisol biomarker increased while whaling activity decreased. We also modelled recent (>1980) anthropogenic perturbations such as fishing activity, ship traffic and climate change to determine effect on stress levels in whales. Linear mixed-effects models of cortisol in cerumen of large baleen whales was used to determine a best fit. Reduced models were compared to the full model using likelihood ratio tests and Akaike Information Criterion after sequentially dropping covariates and assessing significance (P <0.05). Cortisol levels were best supported in the model by whaling counts and moratorium years (i.e. 1972) as significant explanatory variables. This study is the first to retrospectively assess chronic physiological response of large whales to past indirect stressors.

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The effectiveness of computationally modeling mysticete hearing thresholds
(Poster)

Topic
Hearing Studies

Sound source
General (all sources)

Tubelli, Andrew A. (1), Zosuls, Aleks (2), Voysey, Graham (2),
Ketten, Darlene R. (2,3)

There are no current feasible methods to behaviorally or physiologically measure audiograms for baleen whales. We must, instead, rely on models to understand hearing ranges in these species. To date, we have employed finite element modeling (FEM) of the middle ear for two baleen whale species: minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae*). Middle ear models serve as a key component of a more comprehensive model of hearing aimed at estimating the auditory thresholds for baleen whales.
One difficulty with models for whale ears is that physical properties, particularly elasticity and density, of key structures have not been measured for most cetaceans. Those that have been measured show significant species differences. Analyses therefore require that in the absence of known physical property measurements, middle ear parameters for cetacean species must be estimated based on known values for similar tissues in terrestrial species. Parameters for our study were based on the structural similarity of known mammalian tissue analogues for a physiologically-relevant range in order to understand the effects of varying these parameters on the model output. To further test the validity of baleen whale models we are also developing a model for the bottlenose dolphin, an odontocete species with ample live animal auditory threshold measurements to serve as a comparison and control for model results. These methods coupled with the middle ear geometry extracted from imaging can be employed for estimating hearing on other baleen whale or similarly untestable endangered species.

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The International Quiet Ocean Experiment *(Poster)*

Topic
Behaviour response studies (BRS) and population level and ecosystem effects

Sound source
General (all sources)

Tyack, Peter L (1), Frisk, George (2), Boebel, Olaf (3), Chakraborty, Bishwajit (4), de Jong, Christ (5), Miksis-Olds, Jennifer (6), Sagen, Hanne (7), Simpson, Steve (8), Tougaard, Jakob (9), and Vedenev, Alexander (10)

The International Quiet Ocean Experiment (IQOE) is an international scientific program designed to promote research, observations, and modeling to improve understanding of past, present, and future ocean soundscapes and effects of sound on marine organisms. Scientific uncertainty regarding the effects of anthropogenic sound on marine life makes it difficult to balance the need for precaution in protecting marine ecosystems against the potentially large costs to socially important activities such as commercial shipping, offshore energy, and military readiness. IQOE seeks constructive engagement with industry, regulators, nongovernmental organizations, and the public to advance our understanding of trends of sound in the sea and its effects on marine life. The IQOE has a global approach to investigating ocean sound over long time scales, working to ensure that the measurement of sound fields becomes an integrated part of global ocean observations, and supporting the development of data standards. IQOE promotes the development of models and data-enabled hindcasting and forecasting trends in anthropogenic and natural sound sources in the sea. IQOE seeks innovation in systems to detect, classify, and track marine organisms and supports the planning and implementation of regional experiments on effects of sound including those larger in scale than typical BRS studies, with particular focus on abilities to monitor current effects and to forecast future effects of sound on marine life. As with other international research projects, IQOE is organized to fund international planning and implementation, while national scientific communities interested in IQOE solicit research funding from traditional national sources.

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Underwater noise in practice; Seismic surveys in the North Sea *(Poster)*

Topic
Policy developments and other stakeholders perspectives

Sound source
Seismic (air guns)

van Mastrigt, Audrey (1), Kwakkel, Jeroen (1), van Oostveen, Martine (1), Clever, Bert (2)

Royal Haskoning DHV (RHDHV) is leading company in writing ecological assessments and preparing permitting documents for the Dutch Nature Protection Law (Wet Natuurbescherming) specifically for seismic surveys on the Dutch North Sea.

In 2014 RHDHV successfully prepared the first permitting documents on a 3D seismic survey for Hansa Hydrocabons. The seismic survey was successfully conducted in the summer of 2014 in de 4QUADS license blocks G18, H16, M3, and N1 40 km north of Schiermonikoog. Since then RHDHV has written several more ecological assessments for different exploration and production companies.
As knowledge on the impact of underwater noise is developing rapidly the methodology used to assess the impact of the activity on the marine environment needs to continuously be updated. RHDHV has developed a method to determine the impact on marine mammals in collaboration with the appropriate authorities. When new information becomes available in addition with practical experience from previous seismic surveys the method is updated.

RHDHV in collaboration with Oranje Nassau Energie (ONE BV), former Hansa Hydrocarbons, would like to give an insight on underwater noise impacts from seismic airguns from a practical experience. What is needed to get a high quality ecological assessment and maybe more importantly, how do we get there.
And secondly how do impacts and mitigation measure defined on paper work out in the field when conducting the seismic survey.

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18 years of environmental assessment of seismic surveys in Brazil: achievements and challenges *(Poster) – WITHDRAWN*

Topic
Policy developments and other stakeholders perspectives

Sound source
Seismic (air guns)

Vilardo, Cristiano & Viana, Mariana

In Brazil, marine seismic surveys have been subjected to environmental impact assessment process since the year 2000. In these 18 years, Brazilian EA practice evolved from zero to being among world's most advanced frameworks. Beginning in days of very limited knowledge and great controversy, IBAMA was able to develop today's standardized and mandatory mitigation package involving visual and passive acoustic monitoring, as well as a network of formally designated closed areas (seasonal and permanent) for marine seismic surveys. This evolution was inspired by international best practice but also relied upon locally commissioned research.

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Foraging in a noisy world: predator-prey interactions under fluctuating noise conditions

Topic
Effects of sound on marine life, Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field and Population-level, ecosystem level effects (PCOD and other), Tag development/methodological advancement and Dissemination of knowledge

Sound source
Sonar, biological and vessel noise

Visser, Fleur

Artificially elevated sound levels, generated by shipping, naval exercises, construction or exploration, can mask acoustic signals and interfere with foraging and reproductive behaviour. Nevertheless, mitigation efforts are handicapped by key gaps in our knowledge on the effects of noise on populations and food web dynamics. We typically just have evidence for simple behavioural effects on single species. However, pertinent evidence for impact of man-made sounds on top predators and species interactions that are key to food web dynamics is critical for our understanding of noise impact on marine ecosystems and urgently needed to inform managers and regulators.

Using an experimental study on two top predators and two distinct prey guilds, we aim to assess the impact of noise on representative baleen and toothed whale species, hunting for krill/small fishes and squid/large fishes respectively. We do so by experimental elevation of sound levels during foraging bouts, using an innovative combination of four advanced sensors: 1) non-invasive digital archival tags and 2) on-animal camera tags record foraging behaviour, capture rates, body condition, sound levels at the whale and prey targets, 3) a camera-drone visualises whale group dynamics and body size from the air and 4) echo sounders assess prey communities and schooling responses to sounds and predators. Field playbacks are matched with captive experiments assessing fine-scale noise responses of prey. The unique combination of data will reveal whether increased sound levels affect whale foraging efficiency and whether this is due to an effect on predator, prey or both.

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Modelling sound and disturbance maps using the impulsive noise register for assessing cumulative impact of impulsive sound *(Poster)*

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field and Assessment and mitigation software

Sound source
Sonar

von Benda-Beckmann, A.M. (1), de Jong, C.A.F. (1), Prior, M. (1), Binnerts, B. (1), Lam, F.P.A. (1), Ainslie, M.A. (1, 2), Kinneging, N.A. (3), Dekeling, R.P.A. (4,5)

The European Union's Marine Strategy Framework Directive (MSFD) has defined underwater noise as a pollutant, and descriptors of 'Good Environmental Status' specific to the potential adverse effects of noise on marine life have been defined. One concern is whether impulsive sound sources lead to population or ecosystem effects, because of their potential to cause displacement of marine animals. ICES has been commissioned by the OSPAR Commission to set up a register contains information about impulsive noise producing activities by EU member states in a systematic manner. A study was carried out to explore how the impulsive noise register can be used to model the underwater sound field and the disturbance of marine animals accumulated over multiple impulsive sources and source types. The objective of this study was to investigate whether maps based on the underwater sound fields give additional insight into the disturbance of marine life compared to using only maps of the distribution of impulsive noise sources. Simple models were used to map sound fields produced by airgun arrays, underwater explosions, pile driving, sonar and acoustic deterrents. These maps allow for effective assessment and visualization of insights available from the impulsive noise register. Potential challenges related to the detail and resolution of information and categorization of source properties contained in the register are discussed. The results can be used for development of an impact indicator by OSPAR, and can be used by EU member states to define threshold values for impulsive noise producing activities, as required by the MSFD.

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Modelling the masking potential of naval continuous active sonar (CAS) and conventional pulsed sonar in sperm whales

Topic

Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field and Assessment and mitigation software

Sound source
Sonar

von Benda-Beckmann, A.M. (1), Isojunno, S. (2), Wensveen, P.J. (3), Ainslie, M.A. (4), Lam, F.P.A. (1), Kvadsheim, P.H. (5), Tyack, P.L.T. (2), Miller, P.J.O. (2)

Continuous Active Sonar (CAS) is an emerging technology, which has recently been shown to have relevant applications in anti-submarine warfare. Compared to conventional pulsed active sonar (PAS), CAS typically operate at lower source levels compared to PAS, but transmit almost continuously. This may alter the way marine mammals respond to the sonar, and could also increase the potential of masking marine mammal hearing. Auditory masking effects of man-made noise among marine mammals are still poorly understood. To interpret the observed sperm whale behaviour during controlled exposures to CAS and PAS signals, a masking model for the sperm whale echolocation was developed to help identifying signals and acoustic dose levels that may be associated with masking by the sonar. Underlying the model are extrapolations from what is known about masked echolocation in dolphins and porpoises, as little is known about the functional hearing system of sperm whales. The model includes an estimation of the received echo level, the sonar exposures, as well as contributions from reverberation, and ambient noise. The model was used to investigate the theoretical potential for masking in the search phase, and during prey-capture buzzes. We address the uncertainties in existing data on masking in sperm whales, and discuss the potential for using such masking models in combination with the experimental evaluation of masking indicators.

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Beaked whale foraging behavior before, during, and after sonar exposure on a Navy test range

Topic
Controlled exposure experiments (CEE) or Behaviour response studies (BRS) in the field and Passive acoustic monitoring (PAM) / Detection, classification and localization (DCL) and tracking

Sound source
Sonar

Watwood, Stephanie, DiMarzio, Nancy, Morrissey, Ron, Jarvis, Sue, and Moretti, David

There is growing evidence of the impact of mid-frequency active sonar (MFAS) on the behavior of beaked whales. The presence and distribution of echolocation clicks of Cuvier's beaked whales (*Ziphius cavirostris*) were analyzed before, during, and after MFAS events in 2014 and 2015 at the US Navy's Southern California Anti-Submarine Warfare Range. Groups of vocalizing (and therefore likely foraging) beaked whales and the timing of sonar transmissions were recorded on the range's bottom-mounted hydrophone array. Generalized Additive Models were used to evaluate the relationship between sonar presence and beaked whale group vocal activity. Similar to what has been shown at the Navy's Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, the number of vocalizing beaked whale groups decreased during MFAS events, as compared to before and after events when no MFAS was in use. Preliminary results indicate movement of the animals off the range during sonar transmissions and a return of the animals to the range upon cessation of operations. Duration and level of response and duration of recovery to previous levels vary depending on the sonar source type. This analysis adds to the growing body of opportunistic studies demonstrating a clear behavioral response to sonar from whales experiencing a normal tempo of sonar exposure in their natural habitat, despite the variation that would normally be controlled for in experimental studies.

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Overview and update of the Office of Naval Research (ONR) Marine Mammals and Biology (MMB) Program

Topic
Effects of sound on marine life
Technical/tool developments
Monitoring for Marine Life

Sound source
Sonar

Weise, Michael

The Office of Naval Research (ONR) Marine Mammals and Biology (MMB) program supports basic and applied research and technology development related to understanding the effects of sound on marine mammals, including physiological, behavioral, ecological effects and population-level effects. Current program thrusts include, but are not limited to Monitoring and Detection, Integrated Ecosystem Research (including sensor & tag development), Effects of Sound on Marine Life (including behavioral response studies; diving physiology; physiological stress response; hearing; and population consequences of acoustic disturbance), and Models and Databases. A brief overview of the ONR research program will be presented.

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Northern bottlenose whales in an acoustically pristine habitat far from naval ranges respond to close and distant exposures of naval sonar

Topic
Behaviour response studies (BRS) in the field

Sound source
Sonar

Wensveen, PJ (1,2), Isojunno S (2), Hansen RR (3), von Benda-Beckmann (4), Kleivane (5), van IJsselmuide (4), Lam FPA (4), Kvadsheim PH (6), DeRuiter SL (7), Curé C (8), Nakazaki T (2), Tyack PL (2), Miller PJO (2)

Environmental assessments of impacts of naval sonar on marine animals use received level (RL) for predictions of behavioral disturbance. This approach assumes that the effect is driven by RL and not source distance; however, animals may learn to associate exposures from distant sources with lower perceived risk. Indeed, recent studies suggest that cetaceans in areas with regular sonar use may respond less to distant sources than to sources nearby. To investigate the roles of source distance and RL in an area far from regular sonar activity, we conducted controlled exposure experiments (CEEs) with northern bottlenose whales near the island of Jan Mayen, Norway, in 2015 and 2016, using sonar sources at different levels and ranges. Twelve animals were tagged with short-duration, high-resolution DTAGs or medium-duration, depth and movement-recording satellite telemetry tags. In addition, we deployed bottom-moored acoustic recorders to monitor for animal groups in the exposed area. Animals initiated avoidance of the sound source at 0.8 to 28 km, with characteristic responses that resembled previous observations for beaked whales. Independent data analyses of DTAGs and satellite tags indicated that response onset and intensity were better predicted by RL than by source distance. The avoidance threshold SPLs of the northern bottlenose whales ranged 116-129 dB re 1μPa, similar to those of beaked whales on naval training and testing ranges. However, unlike for those whales frequently exposed to naval sonar, there was no indication that source distance modulated the effects of sonar (within 28 km) in this largely pristine acoustic underwater environment.

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Modelling the effect of air gun array noise on marine mammal communication
(Poster)

Topic
Population-level and ecosystem level effects (PCOD and other): modelling spatial extent of masking

Sound source
Seismic (air guns)

Wölfing, Benno (1), Stilz, Peter (2), Gavrilov, Alexander (3), Fischer, Matthias (4), Rasmussen, Marianne (1,5), Schuster, Max (4), Wittekind, Dietrich (4), Erbe, Christine (3), Siebert, Prof. Ursula (1)

Seismic airguns used in scientific surveys in the Southern Ocean produce high-intensity impulsive sounds with most energy concentrated in the low frequency band. This frequency range overlaps with that of many marine mammal vocalizations, especially the songs and calls of baleen whales. In addition to causing temporary or permanent dysfunction of the auditory system and inducing behavioral reactions, airgun noise may therefore interfere with marine mammal communication even at large distances from the source.

In order to assess the spatial extent of masking caused by airgun noise in the Southern Ocean, we first studied the propagation of airgun signals in the Southern Ocean using a parabolic equation approximation. The propagation models were verified based on recordings and metadata for two seismic surveys in the Southern Ocean. Numerical predictions are consistent with the measurement results within a few dBs for the sound exposure and energy spectral levels. Subsequently we studied the ability of a listening animal to detect vocalisations (mixed with recordings of ambient noise in the Southern Ocean) in the absence and presence of propagated airgun noise. The auditory detection process of evaluating cochlear excitation patterns over time was modelled by cross correlating the spectrogram of the incoming sound with a vocalisation search pattern (a hybrid spectrogram of several recordings of the focal vocalisation type). We compare the modelled communication ranges in the presence and absence of airgun noise.

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Predicting cochlear frequency response using mechanical properties of the basilar membrane *(Poster)*

Topic
Hearing Studies, TTS-effects and physiology

Sound source
General (all sources)

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Obtaining audiograms for large marine mammals is not practical. Audiograms for these species can be estimated using post mortem tissue measurements and models. To accomplish this, the hearing apparatus is divided into external, middle, and inner ear systems. These systems are characterized, modeled, integrated, and used to produce an audiogram estimate. In the current study a method to estimate the frequency response of the inner ear was tested on a diverse group of marine and terrestrial mammals with known audiograms. The results suggest the method can be used for mysticete whale cochlear frequency response estimation.

A custom force probe was used to measure the mechanical stiffness at multiple points along the length of the basilar membrane in *Homo sapiens, Meriones unguiculatis, Chinchilla chinchilla, Phocoena phocoena, Tursiops truncatus, Delphinus delphis, Ziphius cavirostris, and Balaenoptera acutorostrata*. Basilar membrane width was obtained by scanning the probe across the width of the basilar membrane. The width and stiffness measurements were input into a model used to compute the center frequency of the measured location on the basilar membrane. The estimates were compared to known audiograms and basilar membrane frequency maps when available. For control species the best frequency estimations were monotonically distributed and within the known ranges of hearing.

Basilar membrane width vs. stiffness was fit to an exponential function for both echo locator species and non-echo locators. The results suggest there is an exponential dependence of stiffness on width for both types of cochleae, although there is a difference in the fit coefficients.

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