Marine Mammal Noise Impact Research and Funding Priorities Workshop Report

January 2025

Shane Guan[1], Sónia Mendes[2], Juliette Lee[1]

[1] Bureau of Ocean Energy Management
[2] UK Joint Nature Conservation Committee

U.S. Department of the Interior
Bureau of Ocean Energy Management
Office of Environmental Programs

CITATION

Guan S, Mendes S, Lee J. 2024. Marine mammal noise impact research and funding priorities workshop report. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 97 p. Report No.: BOEM 2025-001.

ACKNOWLEDGMENTS

Funding for this workshop on Marine Mammal Noise Impact Research and Funding Priorities was provided by the Bureau of Ocean Energy Management's Center for Marine Acoustics (Jill Lewandowski). The authors thank Morgan Martin and Samuel Denes for taking details notes during the workshop. We thank following reviewers who provided valuable inputs to this report to make it much better: Erica Staaterman, Yoko Furukawa, and Paulina Chen. And finally, we thank all the workshop attendees who contributed their time and expertise to the discussion.

COVER

Top: Tagging a whale—Behavioral response study of whales from Navy sonar effects using DTag. Taken in Southern California in 2012 by Shane Guan.

Bottom: Testing minke whale hearing—Low-frequency cetacean audiogram using auditory brain response study in Norway. Taken in 2024 by Erica Staaterman.

Contents

List of Tables

List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
BRS	behavioral response study
CMA	Center for Marine Acoustics
DEFRA	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security & Net Zero
DPS	dynamic positioning system
ESOMM	Effects of Sound in the Ocean on Marine Mammals
ESP	Environmental Studies Program
JIP	Joint Industry Programme
JNCC	Joint Natural Conservation Committee
LMR	Living Marine Resources Program
MMC	Marine Mammal Commission
NMFS	National Marine Fisheries Service
NMMF	National Marine Mammal Foundation
ONR	Office of Naval Research
OESEA	Offshore Energy Strategic Environment Assessment
PAM	passive acoustic monitoring
PCOD	population consequence of disturbance
PTS	permanent threshold shift
Q&A	questions and answers
RDT&E	research, development, test, and evaluation
SEA	Southall Environmental Associates, Inc.
SPL	sound pressure levels
TS	threshold shift
TTS	temporary threshold shift
UBA	Umweltbundesamt: German Environment Agency

Executive Summary

The Bureau of Ocean Energy Management (BOEM), in collaboration with the U.K. Joint Nature Conservation Committee (JNCC), co-organized an in-person half-day workshop on Marine Mammal Noise Impact Research and Funding Priorities (Workshop) on 8 September 2024 in The Hague, Netherlands. The Workshop was planned in conjunction with the Effects of Sound in the Ocean on Marine Mammals conference, which was held 9 – 13 September 2024 in the same area, as many of the key players involved in the field of marine mammal noise impacts were present.

The objective of the Workshop was to bring in funding organizations, marine mammal bioacousticians, regulators, industrial developers, and consultants from a number of countries to assess the state of science and to discuss research and funding priorities on anthropogenic underwater noise effects on marine mammals. The Workshop also provided a platform and opportunity for international funders to identify common interests and needs in this field for collaboration and cost sharing.

The Workshop comprised two sessions. Session 1 of the Workshop started with three presentations by leading marine mammal bioacousticians on the state of the science and future directions and included questions and answers for the presentations. These presentations were the following:

- Assessment of Noise Impacts on Marine Mammals: Acoustic Criteria, Field Observations, Research and Mitigation Priorities (Brandon Southall, Southall Environmental Associates & Douglas Nowacek, Duke University)
- Approaches to Estimate Cumulative Sound Exposure Effects on Hearing in a Real-World Scenarios (Ron Kastelein, SEAMARCO)
- Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts (Dorian Houser, National Marine Mammal Foundation)

Following the state of the science discussion, representatives from six regulatory agencies among four countries[1] provided brief overviews of each agency's evidence and noise management gaps on underwater noise regulations. All countries identified *cumulative and long-term effects* as one of the evidence gaps, followed by *noise from dynamic positioning and crew transport vessel*, which were identified as another evidence gap by two countries (U.S. and Germany). On the noise management gaps side, U.S., U.K., and Germany listed *quiet alternative and noise abatement* as one of the high priorities. Summaries of these overviews are provided in Tables 1 and 2 of the report.

Session 2 of the Workshop was a closed-door session excluding entities that typically receive funding to conduct studies. It started with presentations from six international funders[2] on research and funding

[1] U.S.: BOEM, Marine Mammal Commission, National Marine Fisheries Service; UK: JNCC; Germany: Umweltbundesamt (German Environment Agency); The Netherlands: Rijkswaterstaat.

[2] BOEM (U.S.); ONR (U.S.); Navy Living Marine Resources Program (U.S.); Joint Industry Programme (international); Department for Environment, Food and Rural Affairs (UK); Rijkswaterstaat (The Netherlands).

priorities, followed by discussions among international funders, regulators, and industry on potential collaborations and cost-sharing opportunities to support studies related to marine mammal noise impacts. The main needs identified in this session include the following:

- International collaboration, which is essential as the ocean is shared by many countries
- Overcoming international limitations on funding and cost-sharing mechanisms
- Compiling information on funding cycle requirements for each funding agencies worldwide to facilitate collaboration
- Regular and frequent communication among funders to tackle issues like pooling money together

This Workshop was the first step to reach out to international funders to collaborate and cost share on anthropogenic sound effects related environmental studies. Following the Workshop, BOEM has reached out to a number of funders to gather information on funding mechanisms and funding cycles, which could be used to facilitate future collaboration. BOEM plans to continue engaging with various funders to seek collaboration, cost share, and leverage resources to joint fund studies with mutual interests.

1 Introduction

1.1 Background

Great progress has been made over the past 40 years or so to understand anthropogenic underwater noise impacts on marine mammals. Results from research efforts have provided the scientific basis for regulatory agencies to establish criteria for impact assessment from noise exposure (Guan and Brookens, 2021). However, there are still many research questions that need to be addressed to improve the assessments of underwater noise effects on marine mammals. These questions include, but are not limited to, approaches to assess behavioral effects criteria, calculating cumulative sound exposure levels in a real-world scenario, noise-induced hearing loss from complex sound exposure, auditory masking and potential biological effects, cumulative impact assessments, and estimating marine mammal densities from passive acoustic monitoring (PAM).

Given the limited funding resources and the critical needs to address many of these questions, collaborating and cost sharing with other funders that share similar research interests or information needs are prudent approaches. The U.S. Bureau of Ocean Energy Management (BOEM) has worked with many domestic and international partners to fund many cutting edge research projects that have expanded our understanding on anthropogenic sound effects on marine life and their environment (e.g., Cato et al., 2012; Dunlop et al., 2017, 2020; Dunlop and Noad, 2024; Heaney et al., 2024; Kleivane et al., 2024; Martin et al., 2019). To further expand such collaborative efforts to fill the scientific information gaps needed to protect marine mammals from anthropogenic noise impacts from anthropogenic sources in a cost-efficient manner, BOEM initiated and co-organized a workshop on Marine Mammal Noise Impact Research and Funding Priorities (Workshop) in collaboration with the U.K.'s Joint Nature Conservation Committee (JNCC).

1.2 Objectives of the Workshop

The objective of this Workshop was to bring in funding organizations, marine mammal bioacousticians, regulators (and their advisors), industrial developers, and consultants from a number of countries to assess the state of science of underwater noise effects on marine mammals and to discuss related research and funding priorities. The Workshop also provided a platform and opportunity for international funders to identify common research interests and information needs in this field for collaboration and cost sharing.

2 Workshop Overview

The Workshop was an in-person half-day workshop held on 8 September 2024 at the Bilderberg Europa Hotel Scheveningen, The Hague, Netherlands. The Workshop was planned in conjunction with the Effects of Sound in the Ocean on Marine Mammals conference (ESOMM), which was held 9 – 13 September 2024 in the same area, to take advantage of participation by experts who attended the conference. BOEM's Center for Marine Acoustics (CMA) provided funding for the Workshop venue.

To ensure effective discussion, the Workshop was limited to 40 invited participants who are key players within in the field of marine mammal noise impacts. Workshop participants included marine mammal bioacousticians, international regulators who manage underwater noise from offshore development, industries and militaries whose activities generate underwater noise, and consultants who provide technical and regulatory support on underwater noise related issues. A list of Workshop attendees and their affiliations are provided in Appendix A.

BOEM's CMA Director Dr. Jill Lewandowski offered the opening remarks to welcome the Workshop participants, followed by an introduction by Workshop co-organizer Dr. Shane Guan (BOEM's Environmental Studies Program [ESP]). The introduction presentation is provided in Appendix B. The Workshop comprised two sessions. Session 1 had presentations on the state of the science and future directions by leading marine mammal bioacousticians, and current evidence gaps and noise management challenges in noise regulation by international regulatory agencies. The presentations were followed by questions and answers (Q&A) and discussions on information gaps in regulatory process. Session 2 was a closed-door session excluding entities that typically receive funding to conduct studies. It started with presentations from international funders on funding priorities and budget outlook, followed by discussion among international funders, regulators, and industry to discuss research and funding priorities.

2.1 Workshop Agenda

8 September 2024
12:30 – 16:30 CET

12:30 – 12:35	Welcome and Introduction (Jill Lewandowski & Shane Guan, BOEM)
Session 1.	**State of the Science & Management Challenges**
12:35 – 12:45	Assessment of Noise Impacts on Marine Mammals: Acoustic Criteria, Field Observations, Research and Mitigation Priorities (Brandon Southall, SEA & Douglas Nowacek, Duke University)
12:45 – 13:00	Approaches to Estimate Cumulative Sound Exposure Effects on Hearing in a Real-World Scenarios (Ron Kastelein, SEAMARCO)
13:00 – 13:10	Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts (Dorian Houser, NMMF)

13:10 – 13:40	Q&A and Open Discussions on State of the Science on Marine Mammal Noise Impact Research (Moderator: Shane Guan, BOEM)
13:40 – 13:50	United States Partners in Management of Underwater Noise (Juliette Lee, BOEM; Tiffini Brookens, Marine Mammals Commission; Jolie Harrison, National Oceanic and Atmospheric Administration)
13:50 – 13:55	United Kingdom Noise Management Challenges (Sarah Canning for Sónia Mendes, JNCC)
13:55 – 14:00	Challenges on Noise Regulation and Environmental Compliance in Germany (Klaus Lucke, German Environment Agency)
14:00 – 14:05	Netherlands Noise Management Challenges (Niels Kinneging & Martine Graafland, Rijkswaterstaat)
14:05 – 14:35	Open Discussions on Management Challenges Concerning Underwater Noise Impacts on Marine Mammals (Moderator: Juliette Lee, BOEM)
14:35 – 15:00	Break
Session 2.	**Research / Funding Priorities & Cost-sharing Strategies (closed-door session attended by funders, regulators, and industry groups that fund studies)**
15:00 – 15:10	BOEM's Investment to Understand Noise Impacts on Marine Mammals (Shane Guan, BOEM)
15:10 – 15:20	ONR Investment and Research Priorities (Michael Weise, ONR)
15:20 – 15:30	Living Marine Resources Research, Development, Test, and Evaluation (RDT&E) Program (Mandy Shoemaker, U.S. Navy LMR)
15:30 – 15:40	Sound and Marine Life Programme (Adam Bucki & David Hedgeland, JIP)
15:40 – 15:50	UK Research Programmes to Understand Marine Mammal Acoustic Impacts (Sarah Canning, U.K. Department for Environment, Food and Rural Affairs)
15:50 – 16:00	Wind at Sea Ecological Programme (Niels Kinneging & Martine Graafland, Rijkswaterstaat)
16:00 – 16:30	Q&A and Open Discussions on Research/Funding Priorities and Cost-sharing Strategies (Moderator: Shane Guan)
16:30	Adjourn

3 Workshop Session 1

3.1 State of the Science in Marine Mammal Sound Effects

The first part of Session 1 contained three invited presentations by four leading marine mammal bioacoustics researchers and was followed by Q&A and discussions. These presentations provided a general overview of the state of the science in marine mammal bioacoustics and recommendations on how the new information can be used in the regulatory context. The presentations focused on the following three research areas: (1) marine mammal behavioral response studies (BRS); (2) hearing threshold shift (TS) from cumulative sound exposure; and (3) hearing sensitivity and TS on low-frequency cetaceans.

3.1.1 BOEM Information Needs

The selection of these three topics was based on BOEM's critical information needs concerning marine mammals in the following three areas:

1. **Establishing realistic behavioral effects criteria for marine mammals.** The current behavioral effects criteria used by many countries, including the U.S., was established more than 30 years ago, when there were very limited quantitative data on marine mammal behavioral responses from anthropogenic sound exposure based on empirical research (Guan and Brookens, 2021, 2023). The onsets of behavioral disturbances (or Level B take under the U.S. Marine Mammal Protection Act) were solely based on sound pressure levels (SPLs) for the two binary sound types, i.e., impulsive and non-impulsive sounds. There is no consideration of other factors, such as animals' age, sex, behavioral context, motivation, prior experience, or types of sound sources (Ellison et al., 2012). Over the past two decades, numerous BRS projects utilizing animals-borne tags or other advanced tracking technology from controlled exposure experiments have provided valuable insights on marine mammal behavior and movement when exposed to anthropogenic sound (e.g., Durban et al., 2022; Southall et al., 2012). The results of these studies eventually will lead to the development of more realistic behavioral effects criteria (Southall et al., 2021).

2. **Estimating marine mammal noise-induced TS from intermittent sound source using realistic cumulative sound exposure models.** The existing model to estimate marine mammal auditory effects, such as temporary threshold shift (TTS) and permanent threshold shift (PTS), is based on the accumulation of a given received sound exposure level over a certain duration. In the U.S., this duration is chosen to be 24-hours. This model does not consider auditory recovery during the period when the noise stimulus is off (e.g., Laroche et al., 1989)), nor does it take into account that received sound below certain sound levels would not induce TS, regardless of the exposure duration (i.e., effective quiet) (Ward, 1973; Ward et al., 1976). Without the consideration of these factors in an assessment model, the estimated severity of the effects from sound exposure is expected to be overestimated. A recent online workshop co-organized by JNCC and BOEM explored technical and regulatory approaches to develop more realistic models for cumulative sound exposure assessment (Matei, 2024).

3. **An approach to develop low-frequency cetacean audiogram.** Recent successful field research on minke whale (*Balaenoptera acutorostrata*) hearing, using auditory brainstem response data collected from temporarily restrained wild animals in Norway, resulted in a better understanding of baleen whale hearing (Kleivane et al., 2024). The results of this study may provide the base to develop low-frequency cetacean audiograms and may also provide insights into the development of more realistic TS criteria for baleen whales.

3.2 Presentations by Leading Marine Mammal Bioacousticians

The Workshop invited four leading marine mammal bioacousticians to provide overviews in the state of the science in the following three areas: (1) marine mammal BRS; (2) TS from cumulative sound exposure; and (3) hearing sensitivity and TS on low-frequency cetaceans. The brief summary of the presentations is provided below. The slides from the presentations are in Appendix C at the end of this report. The presentations were followed by Q&A by all participants.

3.2.1 Assessment of Noise Impacts on Marine Mammals: Acoustic Criteria, Field Observations, Research and Mitigation Priorities

Dr. Brandon Southall (SEA, Inc.) and Dr. Douglas Nowacek (Duke University)

Dr. Southall and Dr. Nowacek gave an overview on experimental studies, observations, and monitoring of marine mammal behavioral response, and provided several recommendations on establishing behavioral effects criteria. The presentation noted that animals in the wild exposed to anthropogenic sound are most likely to exhibit behavioral response and that auditory effects, in the form of hearing TS, are very unlikely. The authors also stated that establishing a behavioral effects criteria should not be based on a single factor. Instead, a variety of factors—including animals' life history, motivation, behavioral context, and sound type—should be considered.

3.2.2 Approaches to Estimate Cumulative Sound Exposure Effects on Hearing in a Real-world Scenarios

Dr. Ron Kastelein (SEAMARCO)

Dr. Kastelein described his pilot studies testing the equal-energy hypothesis on captive marine mammals. The results showed that the TTS onset levels varied when the animals were exposed to sound stimuli with the same SPL, same cumulative sound exposure level, and different duty cycles. Dr. Kastelein's slides attached in Appendix C-2 also include details of all the intermittent sound TTS studies conducted at SEAMARCO. These are additional slides that were not presented at the Workshop.

3.2.3 Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts

Dr. Dorian Houser (National Marine Mammal Foundation)

Dr. Houser discussed the pros and cons of different methods to investigate low-frequency cetacean hearing and highlighted the challenges to study low-frequency cetacean hearing threshold shifts.

3.2.4 Q&A and Discussions

The presentations were followed by Q&A and discussions. A summary of the major points is provided below:

- With adequate knowledge concerning which species are particularly sensitive, moderately sensitive, or tolerant, it will be possible to apply data to behavioral response functions.
- Variations from context and life histories of the same species can be adjusted by modelers to fit the behavioral response functions.
- There is a need to understand the difference between animat modelling and reality. For example, environmental context and the in situ soundscape should be considered.
- Complex sound sources ongoing simultaneously are challenging to regulate (e.g., pile driving and dynamic positioning in vessels and commercial shipping).
- Complex sound effects on marine mammal hearing, while a challenging topic to study, is an important gap to explore further.
- Although assessing multiple stressors and effects is challenging, the most direct impacts are likely non-injurious; thus, regulators need to focus on masking and behavioral effects.

3.3 Information Gaps for Managing Underwater Anthropogenic Sound

The second part of Session 1 comprised presentations by six regulatory agencies from four countries on evidence and noise management gaps for managing underwater anthropogenic sound. Agencies that participated in the presentations included BOEM (USA), the Marine Mammal Commission (MMC, USA), the National Marine Fisheries Service (NMFS, USA), JNCC (UK), the German Environment Agency (Umweltbundesamt - UBA, Germany), and Rijkswaterstaat (Netherlands). Section 2.1 provides the presentation titles and presenters. Appendix D provides the presentation slides. The presentations were followed by Q&A and discussions.

3.3.1 Presentations by International Regulators

All countries identified cumulative and long-term effects as evidence gaps for managing underwater anthropogenic sound on marine mammals. Two countries (U.S. and Germany) also identified noise from dynamic positioning system (DPS) and crew transfer vessels from offshore wind development and noise in deep sea from potential deep-sea mining as two of the evidence gaps in regulatory processes. Two U.S. agencies (BOEM and MMC) identified the understanding of exposure to complex sound (sound that has both impulsive and non-impulsive structures), as well as low-frequency cetacean bioacoustics as two additional evidence gaps. Other evidence gaps raised by the international regulatory bodies included noise from floating wind anchor installation, behavioral response from multiple sources, and population level consequences. A summary of the evidence gaps is provided in Table 1.

Table 1. Summary of evidence gaps for managing underwater anthropogenic sound presented by six international regulatory agencies from four countries.

Evidence Gaps	Country (Agency)
Cumulative & long-term effects	U.S. (BOEM); UK (JNCC); Germany (UBA); Netherlands (Rijkswaterstaat)
DPS & crew transport vessel noise	U.S. (BOEM); Germany (UBA)
Noise in deep sea	U.S. (BOEM); Germany (UBA)
Complex sound exposure	U.S. (BOEM, MMC)
Low-frequency cetacean acoustics	U.S. (BOEM, MMC)
Behavioral responses from multiple sources	U.S. (MMC)
Noise from floating wind anchor installation	U.S. (BOEM)
Population level consequence	Germany (UBA)
Response from species besides harbor porpoise	UK (JNCC)
Select exposure/response data	U.S. (NMFS)
SSV & support for quieter sources	U.S. (NMFS)
Temporal/space scale of disturbances	U.S. (NMFS)
Ultrasonic antifouling system noise	Germany (UBA)

Three countries (U.S., UK, and Germany) identified developing quieter alternatives to traditional sound sources (e.g., airgun alternatives) and noise abatement as key management gaps. Additionally, U.S. and Germany also identified the development of behavioral effects criteria as one of the noise management gaps. Two U.S. agencies (BOEM and NMFS) identified providing incentives to developers for techniques that reduce noise output. Other noise management gaps included technology to reduce noise during seismic surveys, mitigation effectiveness, long-term monitoring, etc. A summary of the noise management gaps is provided in Table 2.

Table 2. Summary of noise management gaps for managing underwater anthropogenic sound presented by six international regulatory agencies from four countries.

Noise Management Gaps	Country (Agency)
Quiet alternative and noise abatement	U.S. (BOEM); UK (JNCC); Germany (UBA)
Behavioral criteria	U.S. (NOAA); Germany (UBA)
Incentives	U.S. (BOEM, NOAA)
Estimate repeated exposure	U.S. (MMC)
Harmonization on national, regional & international level	Germany (UBA)
Long-term monitoring	UK (JNCC)
Mitigation effectiveness	U.S. (MMC)
Noise reduction during seismic surveys	U.S. (BOEM)
Noise source characterization	UK (JNCC)
Population level impact assessment	U.S. (MMC)
Risk assessment & management framework	U.S. (NOAA)
Species-specific statutes	U.S. (BOEM)

3.3.2 Q&A and Discussions

The presentations by international regulators were followed by Q&A and discussion on regulatory needs to improve underwater noise management. A summary of major points from the discussions is provided below:

- When modelling a single intense disturbance compared to a longer drawn-out stressor, the model exemplifies that a single shorter event yields lower impacts.
- Challenges exist in interpreting multiple sound sources in sequence or in parallel. It is important to note that the chances of injury from sound exposure are incredibly small.
- An easy opportunity is to collect more acoustic data during the construction of floating wind foundations and semi-submersible foundation.
- Data and information exchange is important, and conferences such as ESOMM are productive settings for discussions. However, there are issues when data is proprietary.
- There is a global need to prioritize evidence gaps and noise management gaps. Jurisdictions have an opportunity to utilize a framework to assess impacts across species.

4 Workshop Session 2

Session 2 of the Workshop was a closed-door session that excluded entities that typically receive researching funding. This session comprised two parts. Part 1 was presentations by six funders from three countries (U.S., UK, and the Netherlands) and one international consortium (Joint Industry Programme [JIP]) on overviews of the funders' investment areas and funding priorities. Part 2 of this session was Q&A and discussion among funders about how to collaborate and cost-share on research projects that have common interests.

4.1 Presentation by Funders

The six funders that presented their investment areas and funding priorities include five government agencies from three countries and one international consortium. These entities are: BOEM (U.S.), Office of Naval Research (ONR, U.S.), Navy Living Marine Resources Program (LMR, U.S.), JNCC (U.K.), Rijkswaterstaat (Netherlands), and JIP. Major points of each presentation are provided below. Presentations are provided in Appendix E.

4.1.1 BOEM's Investment to Understand Noise Impacts on Marine Mammals

Dr. Shane Guan (BOEM)

- BOEM's ESP has been supporting marine mammal noise impact studies since late 1970s.
  - First government agency to fund research on industrial noise impacts to marine mammals
  - Funds research internationally (e.g., Behavioral Response of Australian Humpback Whales to Seismic Surveys, co-fund with JIP)
- Establishing the Center for Marine Acoustics (CMA) in 2020
- BOEM Acoustics Science Strategy (BASS)
- Current ongoing marine mammal acoustics studies
  - Atlantic Regional PAM Network (POWERON)
  - North Atlantic right whale acoustic behavior
  - Low-frequency hearing in cetaceans
- Fiscal Year 2025 Studies Development Plan
  - Distributed acoustic sensing technology for baleen whale monitoring at offshore wind areas
  - Marine mammal hearing TTS and auditory recovery from complex sound exposure
  - Sound source characterization of dynamic positioning systems: Field verification
- BOEM actively seeks collaboration and builds partnerships

4.1.2 ONR Investment and Research Priorities

Dr. Michael Weise (ONR)

- Marine Mammal & Biology Program objective - Invest in basic (6.1) and early applied (6.2) research and technology development to discover and understand the effects of sound on marine mammals.
- Monitoring & Detection:

    - Distributed acoustic sensing (DAS)
    - Detection, classification, localization, and density estimate (DCLDE)
    - Whales from space
    - eDNA
- Behavioral response studies
    - Linking to health, Possible consequences of disturbance (PCoD), cumulative effects
    - Review state of the science
- PCoD / Cumulative effects
    - Bioenergetics workshop – converge on models/assumptions
    - Technology development, health metrics (i.e., epigenetics, -omics)
- Cumulative effects
    - Refine models, additional case studies, quantify/predict Interactions (Additive, Synergistic, Antagonistic)
- Education
    - Internship for equity and inclusion

4.1.3 Living Marine Resources RDT&E Program

Ms. Mandy Shoemaker (LMR)

- LMR: 6.4 applied RDT&E program
    - Improving the best available science
    - Broadening the use of or improving the technology and methods available
- Investment areas:
    - Data to support risk threshold criteria
    - Data processing and analysis tools
    - Monitoring technology demonstrations
    - Standards and metrics
    - Emergent topics
- Hearing research
    - External scientific panel review of current status and future of underwater hearing research
    - Underwater behavioral audiograms to study frequency dependent hearing sensitivity
    - AEP based hearing research
    - Large whale hearing
    - Perceived loudness of signals of differing duration
    - Auditory Masking
- TTS research
    - Frequency dependent TTS onset
    - TTS growth and recovery
    - Signal duty cycle effect on TTS
    - Equal-energy hypothesis
    - Exposure duration effect on TTS

4.1.4 Sound and Marine Life Programme

Mr. Adam Bucki (JIP)

- Mission: To enable healthy, resilient oceans, by increasing our knowledge of how the sound we generate interacts with the ocean ecosystems
  - Develop scientifically based monitoring and mitigation methods
  - Provide a body of peer reviewed, independent science that can inform regulators
  - Continue to ensure safe and efficient operations
  - Continue to evolve by identifying and managing potential challenges
- Current Program
  - Low Visibility Marine Mammal Detection Methods
  - Behavioral Response of Whales to Marine Vibroseis
  - Population Consequence of Disturbance (PCOD) Use for Impact Assessment
  - Mysticete Hearing – Improved Weighting Functions and Thresholds
  - Continuous Versus Impulsive Sound Expert Workshops
- Program Outlook
  - Many topics in line with regulatory and operational needs but key limitations are funds and staff time
  - Strengthening ties to advocacy groups and regulators to high-grade and identify highest priority projects and pool resources
  - Continue science programs but also ensure advocacy based on past projects is robust

4.1.5 UK Research Programmes to Understand Marine Mammal Acoustic Impacts

Dr. Sarah Canning (Department for Environment, Food and Rural Affairs)

- The Crown Estate (TCE) Offshore Wind Evidence & Change Programme (OWEC)
  - Delivered in partnership with the UK Government Department for Environment, Food and Rural Affairs (DEFRA) & Department for Energy Security & Net Zero (DESNZ)
  - Brings together 26 government organizations, industry bodies and environmental NGOs to undertake research to facilitate sustainable and coordinated expansion of offshore wind, while supporting clean, healthy, productive and biologically diverse seas
  - £50 million investment from TCE since launch in 2021, plus £12+ million in partner contributions
- Offshore Wind Environmental Evidence Register (OWEER)
  - UK-wide register of offshore wind evidence gaps
  - Publishes high priority evidence gaps and recommends research themes to address consenting risks for offshore wind
  - High priority themes for marine mammals
    - Responses of marine mammals to operational wind turbines
    - Causes, frequency of occurrence and consequences of PTS and disturbance
    - Noise reduction and mitigation techniques
    - Chronic (long-lasting) effects of noise and disturbance
  - Evidence gaps

        - Noise thresholds for disturbance of pinnipeds
        - Better understanding of uncertainties in noise prediction modelling
        - Noise produced by Floating Offshore Wind (construction & operation)
- Offshore Energy Strategic Environment Assessment (OESEA) research program
    - Managed by the UK Government DESNZ
    - The Strategic Environmental Assessment process considers the environmental implications of planned plan/programs.
    - The OESEA research program has been part of the appraisal program since 1999; this identifies evidence gaps and commissions new research to improve the evidence base for undertaking strategic assessments and support activity specific consenting
    - Between 2010 and 2024 (April) have commissioned 59 projects (18 ongoing) and published 48 research reports, 67 peer reviewed papers, and 3 PhDs
- Offshore Wind Enabling Actions Programme (OWEAP)
    - Three-year government-funded project undertaken by DEFRA
    - Work broken down into themes, one of which focused on underwater noise
    - Culminated in the publication of 15 noise related projects and new policy development
- Scottish Marine Energy Research (ScotMER) Programme
    - Funded by Scottish Government, to improve evidence base around how offshore renewable energy developments may affect the environment
    - Facilitates collaboration between academia, industry statutory advisers, and NGOs evidence gaps and enable/fund targeted research
    - 27 publications since 2020 and 17 projects currently underway
    - Hold regular symposiums showcasing research (free to attend and now online)

4.1.6 Wind at Sea Ecological Programme

Ms. Martine Graafland and Dr. Niels Kinneging (Rijkswaterstaat)

- Wind at Sea Ecological Programme addresses
    - Ecological effects of offshore Wind energy
    - Future effects of policy decisions now
    - Effects on protected species
- Themes
    - Coastal and sea birds – collisions, habitat loss
    - Migratory birds – collisions, barriers
    - Bats – collisions during North Sea crossing
    - Marine mammals – underwater noise, habitat suitability
    - Ecosystem effects – large-scale changes of the ecosystem
    - Use of knowledge – Framework Ecology and Cumulation (KEC)
- Marine Mammal Issues
    - Underwater noise
    - Direct effects (construction and operational)
    - Indirect effects (e.g., unexploded ordnance clearance)
    - Habitat suitability of wind farms
    - Population studies

- Other Programmes and Projects Regarding Underwater Sound/Marine Mammals
  - Monitoring
  - Research Fundamental Science
  - Research Applied Science
- Funds by the EU
  - LIFE+
  - Interreg
  - Horizon Europ
  - European Maritime and Fisheries Fund

4.2 Q&A and Discussions

The presentations by international funders were followed by Q&A and discussion on collaboration and cost sharing among various funders to support marine mammal noise impact studies. A summary of major points from the discussions is provided below:

- International collaboration is essential.
- There is a need to overcome international limitations on funding and cost-sharing mechanisms.
  - In the U.S., funds from different sources often cannot mix, thus there is a need different statement of work (BOEM's example: either fund different part of the project or provide fund to one entity to manage subcontract(s)).
- There is a need to compile information on funding cycle requirements for each funding agencies worldwide to facilitate collaboration.
- Regular and frequent communication among funders is needed to tackle issues like pooling money together is valuable.
- There is a need to keep research facilities open that conduct captive animal hearing work.
- There is a long-term need of the study of cumulative effects amongst multiple partners.

5 Conclusion

Overall, the workshop on Marine Mammal Noise Impacts Research and Funding Priorities was very productive. The presentations and discussions centered around the state of the science, regulatory needs and challenges, as well as international collaborations among funders and gained useful insights on information gaps required to manage underwater sound from human activities. It also provided an opportunity for international funders to further communicate and collaborate.

Workshop organizers presented the results of the Workshop at the ESOMM Conference on September 12, 2024. The presentation is provided in Appendix F.

6 References

Cato, D. H., Noad, M. J., Dunlop, R., McCauley, R. D., Gales, N. J., Salgado Kent, C., Kniest, E., et al. (2012). “Project BRAHSS: behavioural response of Australian humpback whales to seismic surveys,” 2012 Conf. Aust. Acoust. Soc.

Dunlop, R. A., McCauley, R. D., and Noad, M. J. (2020). “Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts,” Mar. Pollut. Bull., 154, 111072. doi:10.1016/j.marpolbul.2020.111072.

Dunlop, R. A., Noad, M. J., McCauley, R. D., Kniest, E., Slade, R., Paton, D., and Cato, D. H. (2017). “The behavioural response of migrating humpback whales to a full seismic airgun array,” Proc. R. Soc. B Biol. Sci., 284, 20171901. doi:10.1098/rspb.2017.1901.

Dunlop, R., and Noad, M. (2024). “Male humpback whales switch to singing in the presence of seismic air guns,” Commun. Biol., 7, 1–11. doi:10.1038/s42003-024-06908-w.

Durban, J. W., Southall, B. L., Calambokidis, J., Casey, C., Fearnbach, H., Joyce, T. W., Fahlbusch, J. A., et al. (2022). “Integrating remote sensing methods during controlled exposure experiments to quantify group responses of dolphins to navy sonar,” Mar. Pollut. Bull., 174, 113194. doi:10.1016/j.marpolbul.2021.113194.

Ellison, W. T., Southall, B. L., Clark, C. W., and Frankel, A. S. (2012). “A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds,” Conserv. Biol., 26, 21–28. doi:10.1111/j.1523-1739.2011.01803.x.

Guan, S., and Brookens, T. (2021). “The use of psychoacoustics in marine mammal conservation in the United States: from science to management and policy,” J. Mar. Sci. Eng., 9, 507. doi:10.3390/jmse9050507.

Guan, S., and Brookens, T. (2023). “An overview of research efforts to understand the effects of underwater sound on cetaceans,” Water Biol. Secur., 2, 100141. doi:10.1016/j.watbs.2023.100141.

Heaney, K. D., Ainslie, M., Murray, J. J., Heaney, A. J., Miksis-Olds, J., and Martin, B. (2024). “Regional soundscape modeling of the Atlantic Outer Continental Shelfa),” J. Acoust. Soc. Am., 156, 378–390. doi:10.1121/10.0026476.

Kleivane, L., Kvadsheim, P. H., Vinje, A. V. P., Mulsow, J., Ølberg, R. A., Teilmann, J., Harms, C., et al. (2024). “Capture and release of minke whale offers new research opportunities, including measurements of mysticete hearing,” Aquat. Mamm., 50, 352–368.

Laroche, C., Hétu, R., and Poirier, S. (1989). “The growth of and recovery from TTS in human subjects exposed to impact noise,” J. Acoust. Soc. Am., 85, 1681–1690. doi:10.1121/1.397957.

Martin, S. B., Morris, C., Bröker, K., and O'Neill, C. (2019). "Sound exposure level as a metric for analyzing and managing underwater soundscapesa)," J. Acoust. Soc. Am., 146, 135–149. doi:10.1121/1.5113578.

Matie, M. (2024). Towards improved cumulative sound exposure estimates for marine mammals exposed to intermittent underwater sounds – workshop outcomes. Report number SMRUC-JNC-2024-010 provided to JNCC.

Southall, B. L., Moretti, D., Abraham, B., Calambokidis, J., DeRuiter, S. L., and Tyack, P. L. (2012). "Marine mammal behavioral response studies in southern California: advances in technology and experimental methods," Mar. Technol. Soc. J., 46, 48–59. doi:10.4031/MTSJ.46.4.1.

Southall, B. L., Nowacek, D. P., Bowles, A. E., Senigaglia, V., Bejder, L., and Tyack, P. L. (2021). "Marine mammal noise exposure criteria: Assessing the severity of marine mammal behavioral responses to human noise," Aquat. Mamm., 47, 421–464.

Ward, W. D. (1973). "The concept of 'effective quiet,'" J. Acoust. Soc. Am., 54, 327. doi:10.1121/1.1978309.

Ward, W. D., Cushing, E. M., and Burns, E. M. (1976). "Effective quiet and moderate TTS: implications for noise exposure standards," J. Acoust. Soc. Am., 59, 160–165. doi:10.1121/1.380835.

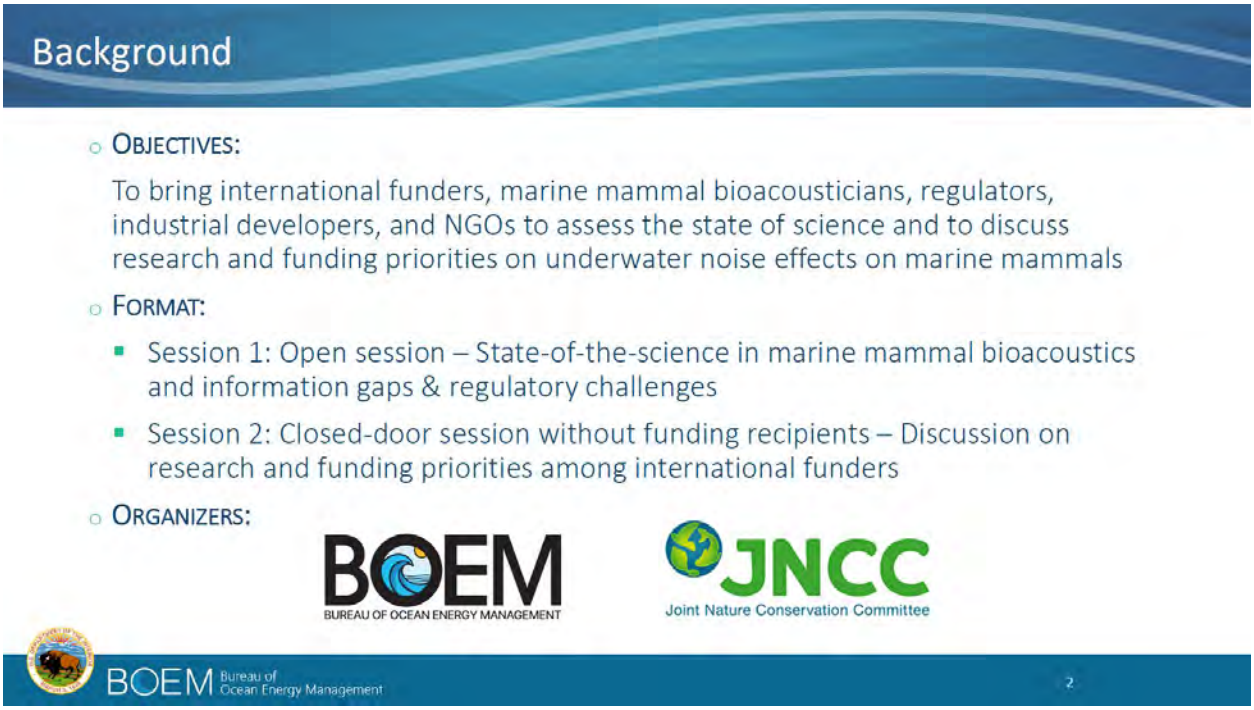
Appendix A: Workshop Participants and Sessions Attended

Name	Affiliation	Session 1	Session 2
Cormac Booth	Sea Mammal Research Unit	✓	-
Tiffini Brookens	U.S. Marine Mammal Commission	✓	✓
Adam Bucki	JIP Sound & Marine Life	✓	✓
Olivia Burke	Carbon Trust	✓	✓
Benjamin Colbert	U.S. Navy, OPNAV N4I	✓	✓
Sarah Canning	U.K. Department for Environment, Food & Rural Affairs	✓	✓
Alexander Conrad	U.S. Bureau of Ocean Energy Management	✓	✓
Daniel Costa	University of California Santa Cruz	✓	-
Leah Davis	U.S. National Marine Fisheries Service	✓	✓
Willem De Moor	JPI Oceans	✓	✓
Sam Denes	U.S. Bureau of Ocean Energy Management	✓	✓
Martine Graafland	The Netherlands Rijkswaterstaat, Ministry of Infrastructure and Water	✓	✓
Shane Guan	U.S. Bureau of Ocean Energy Management	✓	✓
Catriona Harris	University of St. Andrews / CREEM	✓	-
Jolie Harrison	U.S. National Marine Fisheries Service	✓	✓
David Hedgeland	JIP Sound & Marine Life	✓	✓
Dorian Houser	National Marine Mammal Foundation	✓	-
Kim Hum	Hawaiian Islands Humpback Whale National Marine Sanctuary	-	✓
Ryan Jones	University of California Santa Cruz	✓	-
Carina Juretzek	German Federal Maritime & Hydrographic Agency	✓	✓
Ron Kastelein	SEAMARCO	✓	-
Niels Kinneging	The Netherlands Rijkswaterstaat, Ministry of Infrastructure and Water	✓	✓
Frans-Peter Lam	TNO	✓	-

Name	Affiliation	Session 1	Session 2
Marc Lammers	Hawaiian Islands Humpback Whale National Marine Sanctuary	-	✓
Juliette Lee	U.S. Bureau of Ocean Energy Management	✓	✓
Jill Lewandowski	U.S. Bureau of Ocean Energy Management	✓	✓
Alex Loureiro	EnerGeo Alliance	✓	✓
Klaus Lucke	German Environment Agency	✓	✓
Morgan Martin	U.S. Bureau of Ocean Energy Management	✓	✓
Jan Matthiesen	Carbon Trust	✓	✓
Craig McPherson	JASCO	✓	-
Douglas Nowacek	Duke University	✓	-
Federica Pace	JASCO	✓	-
Molly Reeve	U.S. Bureau of Ocean Energy Management	✓	✓
Rune Roland	The Norwegian Water Resources and Energy Directorate	✓	✓
Amy Scholik-Schlomer	U.S. National Marine Fisheries Service	✓	✓
Mandy Shoemaker	U.S. Navy Living Marine Resources Program	✓	✓
Brandon Southall	SEA, Inc.	✓	-
Frank Thomsen	DHI	✓	-
Michael Weise	U.S. Office of Naval Research	✓	✓

Appendix B: Workshop Introduction Presentation

B-1. Workshop on Marine Mammal Noise Impact Research & Funding Priorities (Shane Guan)



Agenda

- SESSION 1: OPEN SESSION

  12:35-13:40 State-of-the-science presentations and discussion

  13:40-14:35 Management challenges presentations and discussion

- BREAK

  14:35-14:50

- SESSION 2: CLOSED-DOOR SESSION WITHOUT FUNDING RECIPIENTS

  14:50-15:50 Presentations on investment and research priorities from a number of international funders

  15:50-16:30 Discussions on research/funding priorities & cost-sharing strategies

- ADJOURN

  16:30

Suggested Discussion Topics/Questions

- DISCUSSION RELATED TO STATE-OF-THE-SCIENCE

  1. What is the next step to bring closer to establishment of marine mammal behavioral effects criteria?
  2. What is the next step to develop a process that can be used to estimate cumulative sound exposure effects in a real-world scenario?
  3. Can the newly obtained minke whale hearing data be readily used to establish low-frequency baleen whale hearing thresholds?
  4. What is the next step to develop a process that can be used to estimate marine mammal TS from complex sound (sound that includes both impulsive and non-impulsive structures) exposure?

Suggested Discussion Topics/Questions

- DISCUSSION RELATED TO REGULATORY CHALLENGES

1. What are the five critical information gaps that are most urgently needed to address and/or improve regulatory compliances and environmental assessments?
2. Among these critical information gaps, what are the low-hanging fruits that can be addressed with minimum investment, and what require long-term investment?
3. Are there any other information gaps that were not identified or cannot be answered by research presented earlier that are particularly important for regulatory compliance (e.g., auditory masking, physiological stress, questions related on monitoring/mitigation, marine mammal density estimation, sound source characterization, sound propagation)?

BOEM Bureau of Ocean Energy Management

5

Suggested Discussion Topics/Questions

- DISCUSSION RELATED TO RESEARCH AND FUNDING PRIORITIES

1. What are the five top priority research topics that are needed to address and/or improve regulatory compliances and environmental assessments?
2. What are the funding levels and forecasts in the foreseeable future for each funder?
3. How can we collaborate and cost-share to support research topics that have common interest?
4. Way forward: What is the best way to establish a mechanism for future coordination and communication in collaboration and cost-sharing?

BOEM Bureau of Ocean Energy Management

6

Workshop Report Out

THURSDAY, 12 SEPTEMBER, 16:00

BOEM Bureau of Ocean Energy Management

7

BOEM

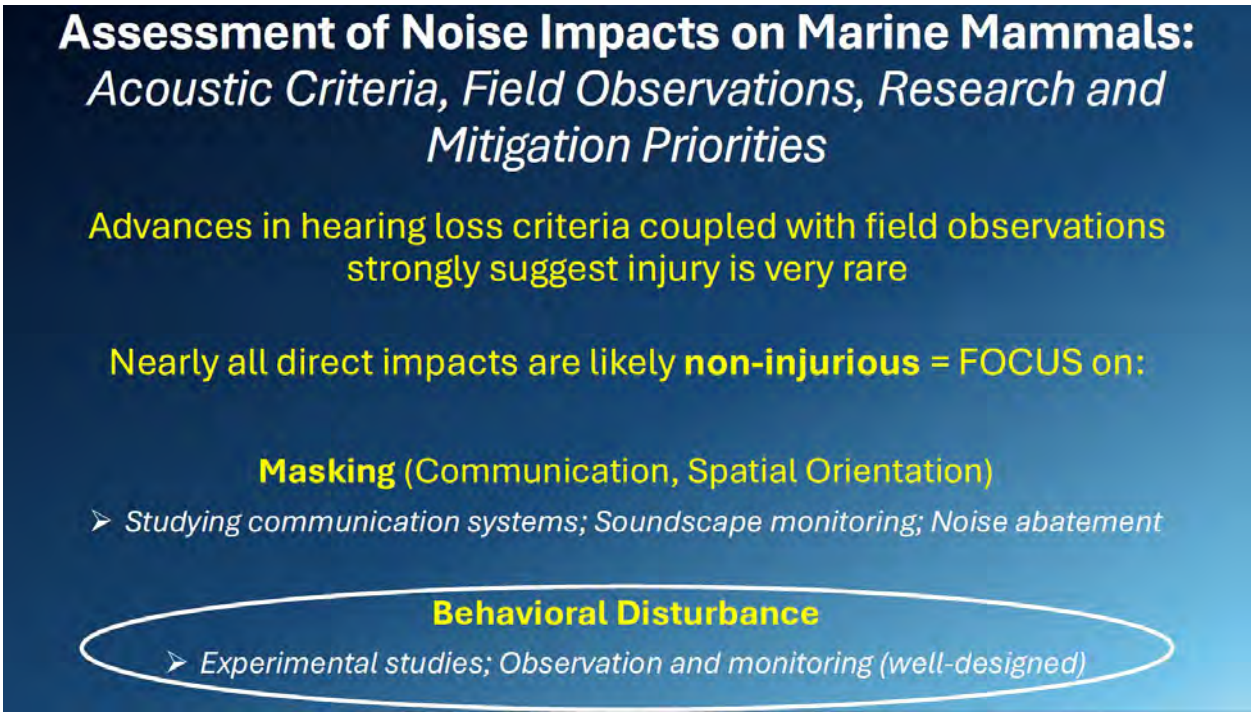
Bureau of Ocean Energy Management

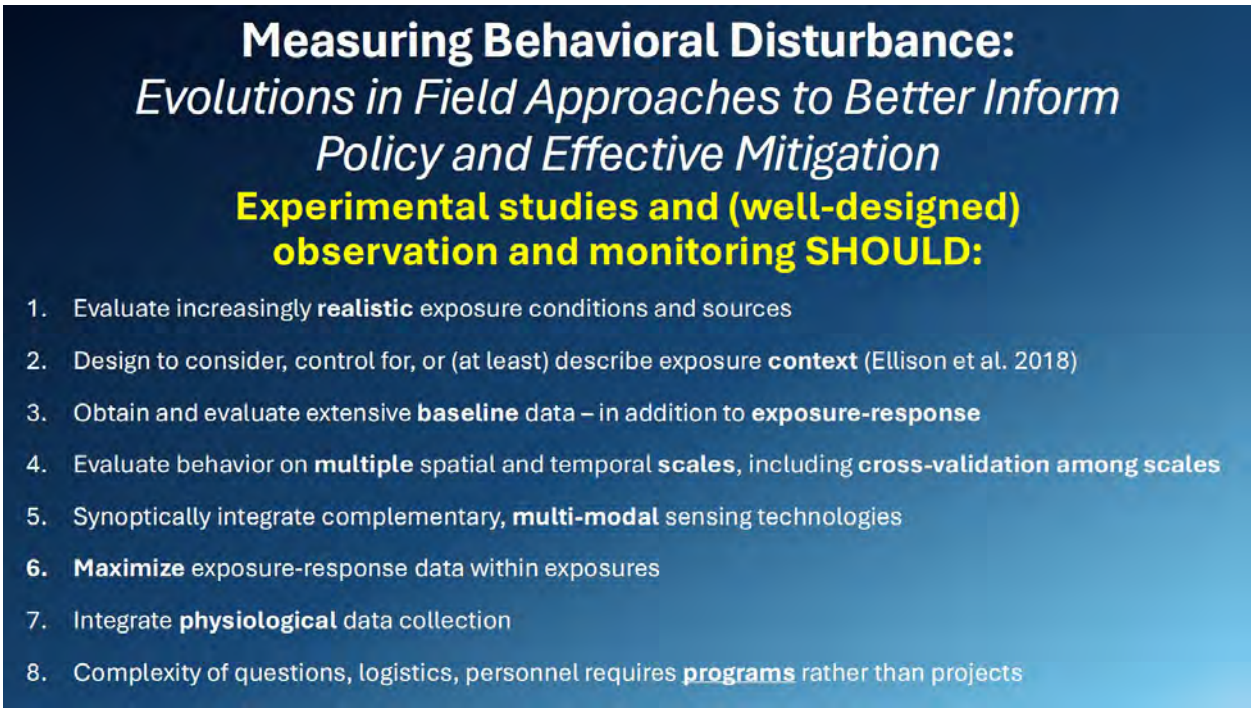
BOEM.gov

Shane Guan, Ph.D., shane.guan@boem.gov

Appendix C: Presentations by Marine Mammal Bioacousticians

C-1. Assessment of Noise Impacts on Marine Mammals: Acoustic Criteria, Field Observations, Research and Mitigation Priorities (Brandon Southall & Douglas Nowacek)





Recommendations on Establishing Behavioral Effects Criteria

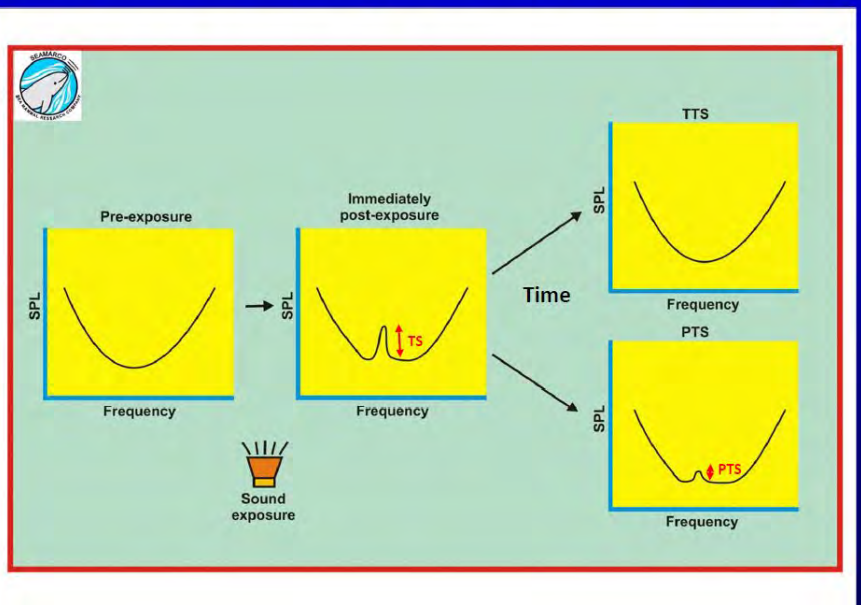
Distinction: Criteria for when to decide there has been a behavioral response (impact?) OR blanket exposure threshold?

1. **Probabilistic** functions for responses that consistently incorporate *inter alia*:
   a. Relative sensitivity categorically (not necessarily taxonomic 'hearing groups')
   b. Sound type categories (i.e., on beyond impulsive vs. non-impulsive - see Southall et al. 2021)
   c. Life history elements (more sensitive sex/age classes; seasonality)
2. Facilitate (establish?) mechanisms/pathways for incorporating new information quickly/regularly

C-2. Approaches to Estimate Cumulative Sound Exposure Effects on Hearing in a Real-world Scenarios (Ron Kastelein)[3]

[3] This slide deck also includes details of all the intermittent sound TTS studies conducted at SEAMARCO. These are additional slides that were not presented at the Workshop.

What is a hearing Threshold Shift (TS)?



2

How do you measure TTS?

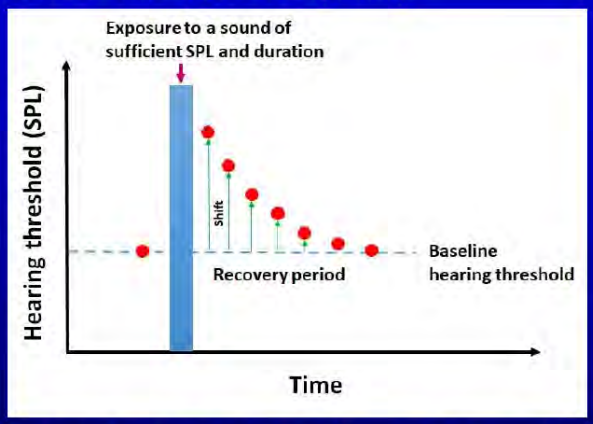
Pre-noise exposure (baseline) hearing threshold

Noise exposure (Rock concert)

Post-exposure hearing threshold

3

- Hearing shift (TTS and PTS) depends on the level of the sound (SPL) and the duration of the exposure (time).



- The unit that contains both SPL and time is Sound Exposure Level (SEL).
- EEH: Short continuous high-amplitude sounds with the same SEL as longer continuous low-amplitude sounds elicit the same TTS.

4

Issues



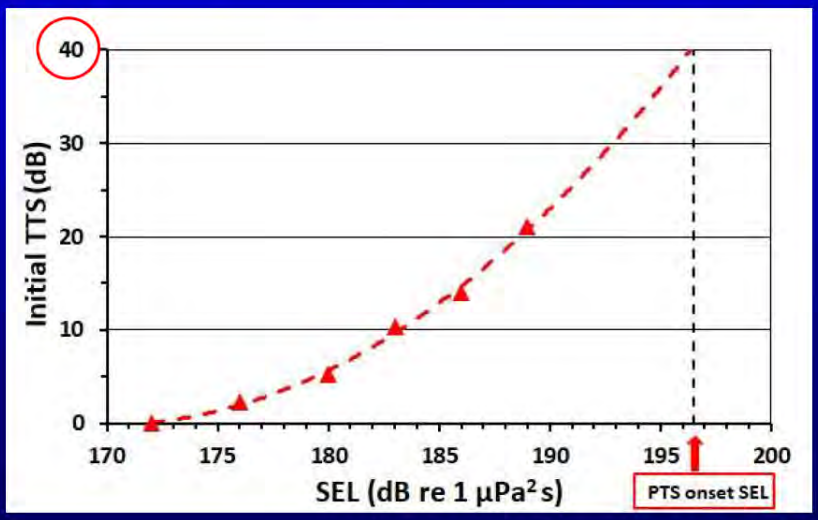
- High underwater SPLs can be generated during anthropogenic activities at sea (pile driving, naval sonar, seismic surveys).
- This may affect the hearing of marine mammals in the vicinity of the sound sources.

- To protect the animals' hearing, governments are setting limits to the sound levels animals can be exposed to.
- Permanent hearing threshold shift (PTS) has been identified as an indicator of sound impact, and should be avoided, as it is irreversible.
- Testing PTS on marine mammals is unethical, and therefore temporary hearing threshold shift (TTS) measurements are used to predict sound exposure levels that cause PTS.

5

Estimating PTS onset SEL from TTS measurements

Assumption: PTS occurs when the shift is 40 dB



6

Introduction

For Environmental Impact Assessment, information is needed on the potential effects of continuous and intermittent anthropogenic sound on hearing of marine mammals

Anthropogenic intermittent sound sources with high SPLs

Pile driving

IPI: 1.5 s

Fish-finding sonar

IPI: 0.1 s

Naval PAS

IPI: 9 s (MFAS)

Seismic surveys

IPI: 10 s

7

TTS studies with intermittent sounds

	Species	Number of studies	Fatiguing sound	Study location
	Bearded seal	1	Airgun	Long Marine Lab
	Bottlenose dolphin	4	Sonar, airgun, tones, noise bands	U.S. Navy labs
	Harbor porpoise	6	Sonar, airgun, impact pile driving	SEAMARCO
	Harbor seal	1	Impact pile driving	SEAMARCO
	California sea lion	2	Noise bands	SEAMARCO

Sound types, signal durations, duty cycles determined by anthropogenic underwater sounds

8

TTS studies with impulsive sounds

- **Impulsive sound is broadband.**
- **Most of the energy is in the lower part of the spectrum (< 1 kHz).**
- **Marine mammals hearing is relatively unsusceptible to LF sound.**
- **Therefore, in laboratories it has been impossible/very difficult to elicit TTS with impulsive sounds (single, and even multiple).**

9

Intermittent 1 2 3 4 5 6 7

Continuous 1 2 3 4 5 6 7

Does an intermittent sound, with the same SELcum as a continuous sound, produce the same TTS?

NO!

Reason: SELcum does not incorporate recovery between intermittent sounds.

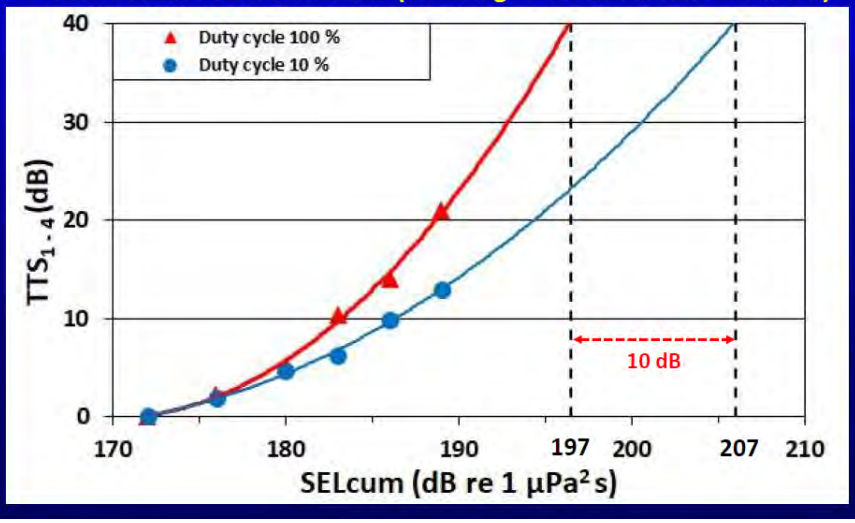
Thus, using SELcum to predict TTS after intermittent sound is conservative and overly restrictive.

10

TTS due to intermittent sound in harbor porpoises

Naval MFAS: 1-s, 6-7 kHz down-sweeps, SPL 166 dB re 1 µPa, duty cycles 10% & 100%. At 10% DC: IPI 9 s.

Estimation of PTS onset SELcum (assuming PTS occurs around 40 dB TTS)



A criterion based on TTS growth due to continuous sound would be 10 dB too strict for the same (SPL & frequency), but intermittent, sound with a DC of 10 %

11

Conclusion: Duty cycle matters !

- Clear evidence of recovery of hearing in pauses.
- Most anthropogenic sounds are not continuous.
- The SPLs in the IPIs of anthropogenic sound could still contribute to TTS growth or delay recovery.
- This is a new area of research.

12

Example of a study with higher SPLs in the IPIs

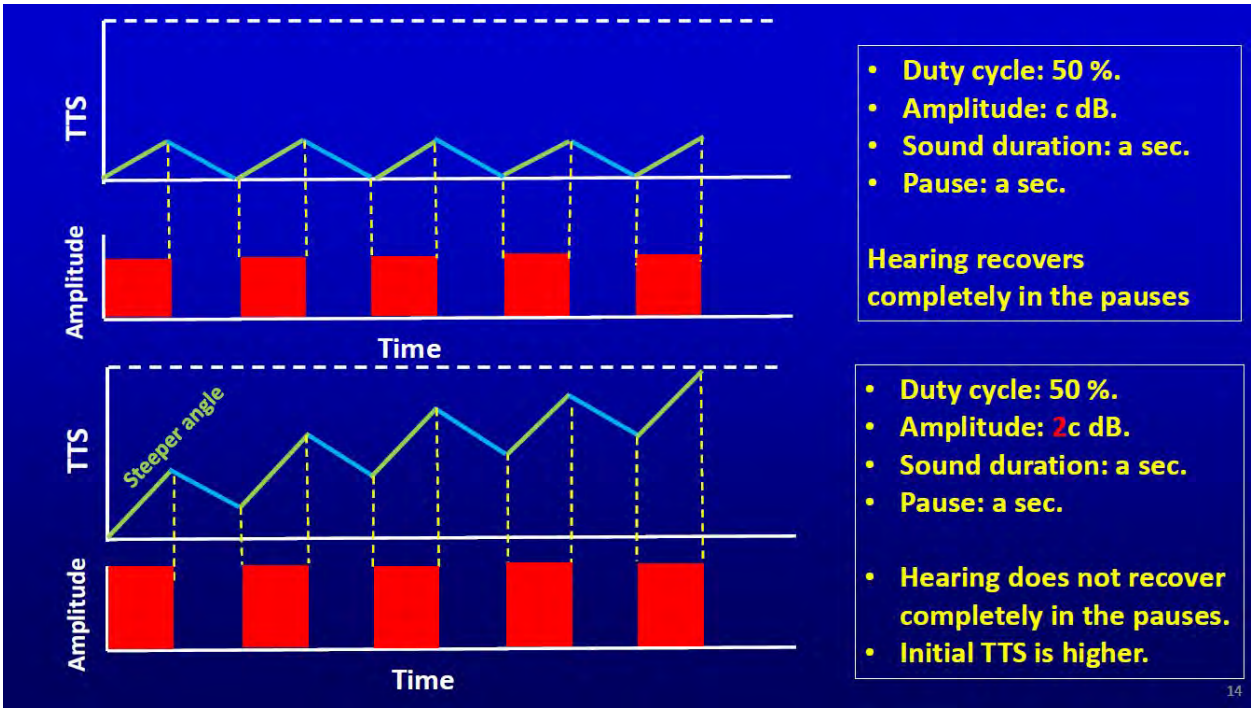
TTS in h porpoises due to sound with a duty cycle of 50%, composed of different signal duration and signal interval combinations ("duty cycle composition")

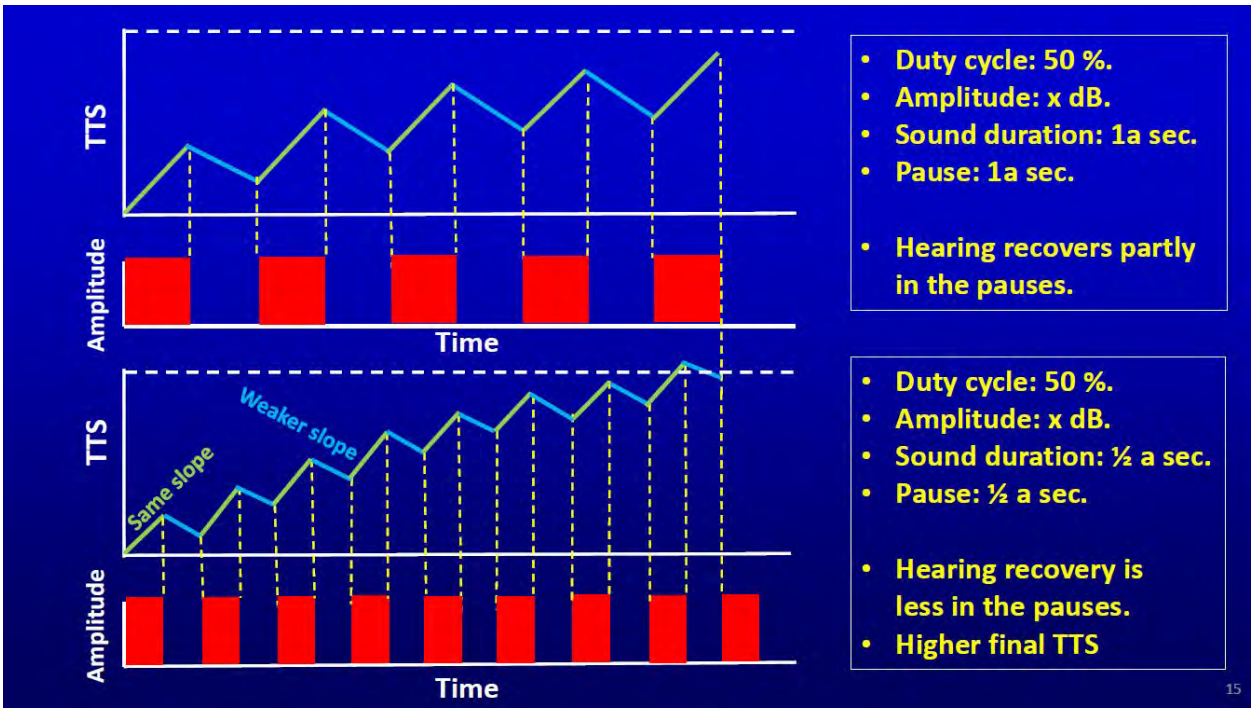
Signal duration = pause duration

Fatiguing sound: 1/6th-octave noise band at 8 kHz

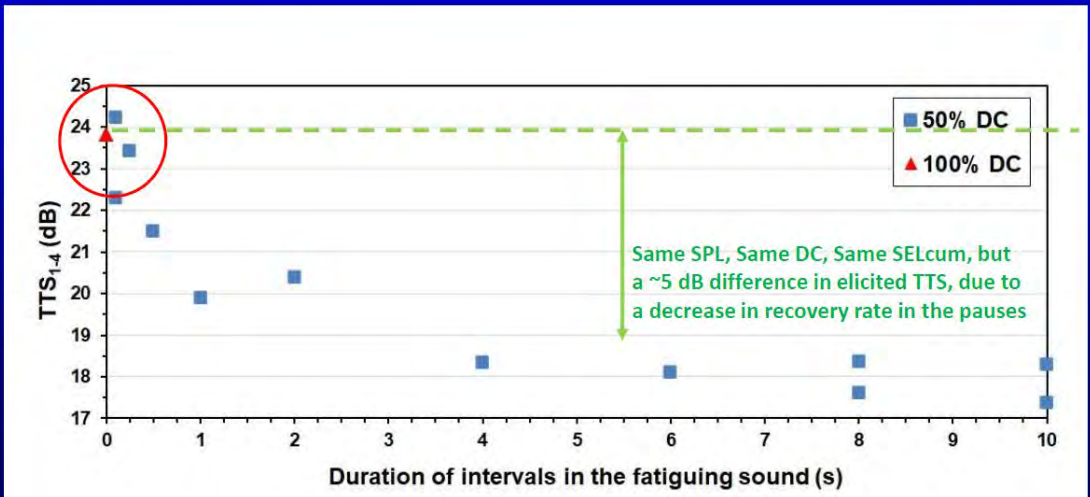
Unpublished data, ms in prep

13


TTS
Amplitude
Time
TTS
Steeper angle
Amplitude
Time
• Duty cycle: 50 %.
• Amplitude: c dB.
• Sound duration: a sec.
• Pause: a sec.
Hearing recovers completely in the pauses
• Duty cycle: 50 %.
• Amplitude: 2c dB.
• Sound duration: a sec.
• Pause: a sec.
• Hearing does not recover completely in the pauses.
• Initial TTS is higher.
14


TTS
Amplitude
Time
TTS
Weaker slope
Same slope
Amplitude
Time
• Duty cycle: 50 %.
• Amplitude: x dB.
• Sound duration: 1a sec.
• Pause: 1a sec.
• Hearing recovers partly in the pauses.
• Duty cycle: 50 %.
• Amplitude: x dB.
• Sound duration: ½ a sec.
• Pause: ½ a sec.
• Hearing recovery is less in the pauses.
• Higher final TTS
15

TTS due to intermittent sound in harbor porpoises: Effect of duty cycle composition



16

- Duty cycle composition matters below a certain inter-pulse interval.
- The reduced recovery in the pauses is probably due to reflections, which play a relative large role in short inter-pulse intervals.
- These reflections have a lower SPL than the original direct sound.
- Reflections also occur in seas and oceans (or just a higher background noise level).
- This study shows the need for knowledge of "Effective quiet"

17

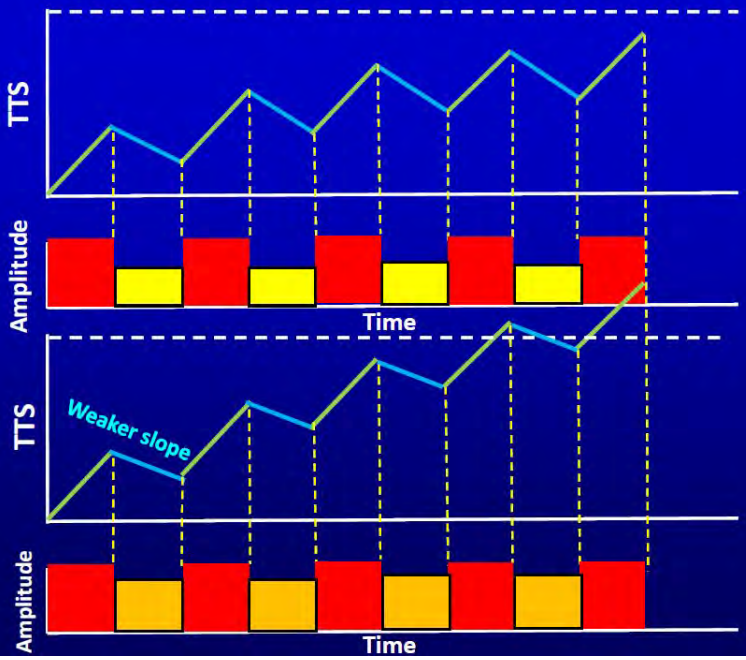
Effective quiet

"Effective quiet" is an SPL threshold below which sound energy does not contribute to the growth of TTS, or delay the recovery of TTS (Ward et al., 1976)

Ward, W.D., Cushing, E.M., and Burns, E.M. (1976). "Effective quiet and moderate TTS: Implications for noise exposure standards", J. Acoust. Soc. Am., 59 (1), 160-165.

18

Effective quiet (potential effect of reverberations)

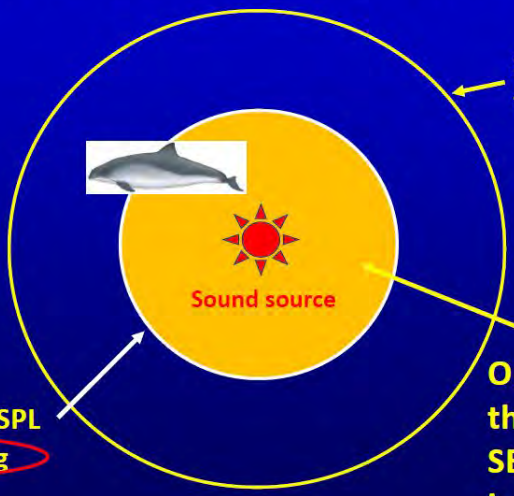


- Duty cycle: 50 %.
- Amplitude: x dB.
- Signal duration: 1a sec.
- Pause: 1a sec.
- SPL in pauses is below the effective quiet threshold SPL; does not reduce recovery rate.
- Hearing recovers partly in the pauses

- Duty cycle: 50 %.
- Amplitude: x dB.
- Signal duration: 1a sec.
- Pause: 1a sec.
- SPL in pauses is above the effective quiet threshold SPL; it reduces the recovery rate.
- Hearing recovers partly in the pauses

19

When swimming away from a sound source, when does sound energy not cause TTS any more, or reduce the recovery rate ?
(i.e., an SPL at which, in impact assessments, SELcum should stop increasing)



20

Suggestions for "TTS due to intermittent sound" research

- Studies on the interaction between signal durations and pauses on TTS.
- Studies on effective quiet thresholds in several marine mammal species at frequencies across their hearing ranges.
- Examine the relationship between intermittent sounds and the effective quiet thresholds.
- Design projects to provide data to support the development of regulations, at least for well-defined sound types.

21

Funding agencies

livingmarine RESOURCES — SCIENCE · STEWARDSHIP · NAVY READINESS

E&P SOUND & MARINE LIFE PROGRAMME

Ministry of Infrastructure and the Environment

International Association of Oil & Gas Producers

Ministry of Economic Affairs, Agriculture and Innovation

Naval sonar & Fundamental sounds

Airgun

Percussion pile driving

22

SEAMARCO

Applied research for marine conservation

rk@seamarco.nl

SEAMARCO — SEA MAMMAL RESEARCH COMPANY

23

TTS studies with intermittent sounds

Species	Sound	Freq. range	Sound type	Signal duration	Inter pulse interval	Exposure duration	SPL/SEL	Duty cycle(s)	Reference:
Bearded seal 	Seismic airgun	20 Hz-20 kHz (Max at 100 Hz	Impulsive	Not reported	10 s	20-100 s	SEL cum 191-195 dB re 1 $\mu Pa^2.s$	2, 4 and 10 shots	Sills et al., 2020
Bottlenose dolphin 	MFAS	3-4 kHz & harmonics	ping	0.5 s	24 s	3-ping blocks. 0.1-30 min	203 dB re 1µPa 214 dB re 1 $\mu Pa^2.s$		Mooney et al., 2009
,,	Seismic airgun	1 Hz-20 kHz	Impulsive	Not reported	10 s	100 s	SEL: 193-195dB re 1 $\mu Pa^2.s$	10 shots	Finneran et al., 2015
,,	Tones	3 kHz	Tone (CW)	16 s and 64 s (1 tone)	224 s	1 x 16 s 4 x 16 s 1 x 64 s	SPL: 192 dB re 1µPa	7%	Finneran et al., 2010
,,	1/6-octave BW	at 8 kHz	Impulsive	10 ms	2.5-40 s	1.4-53.2 min	175-180 dB re 1µPa	40-2560 pulses	Mulsow et al., 2023

24

TTS studies at SEAMARCO with intermittent sounds

Species 	Sound	Freq. range	Sound type	Signal duration	Inter pulse interval	Exposure duration	SPL/SEL	Duty cycle(s)	Reference: Kastelein et al.
Harbor porpoise	MFAS	6-7 kHz	Down-sweep	1 s	9 s	60 min	SPL 166 dB	10 & 100%	2015
,,	Impact pile driving	Broad-band	Impulsive	124 ms	1.3 s	60 min	SELss 146 dB	9.5%	2015
,,	LFAS	1-2 kHz	Down-sweep	1s	0-19 s	60 min	SPL 168 dB	5-100%	2016
,,	Impact pile driving	Broad-Band	Impulsive	124 ms	1.3 s	15-360 min	SELss 145 dB	9.5%	2016
,,	53-C sonar	3.5-4.1 kHz	2 sweeps & 1 tone	1600 ms	60 ms	60 min	SPL 142 dB	96%	2017
,,	Airgun	Broad-band	Impulsive	78 ms	17 s	10 & 20 shots	SELss 175 dB SELcum 188 & 191 dB	0.45%	2017

25

TTS studies at SEAMARCO with intermittent sounds

Species 	Sound	Freq. range	Sound type	Signal duration	Inter-pulse interval	Exposure duration	SPL/SEL	Duty cycle(s)	Reference: Kastelein et al.
Harbor seal	Impact pile driving	Broad-band	Impulsive	127 ms	1.3 s	180-360 min	SELss 151 dB	9.5%	2018

Species 	Sound	Freq. range	Sound type	Signal duration	Inter-pulse interval	Exposure duration	SPL/SEL	Duty cycle(s)	Reference: Kastelein et al.
California sea lion	Noise	1/6 oct at 4 kHz	Noise	1600 ms	0-62 s	60 min	SPL 169 dB	2.5-100%	2021
"	Noise	1/6 oct at 8 kHz	Noise	1600 ms	0-62 s	60 min	SPL 154 dB	2.5-100%	2022

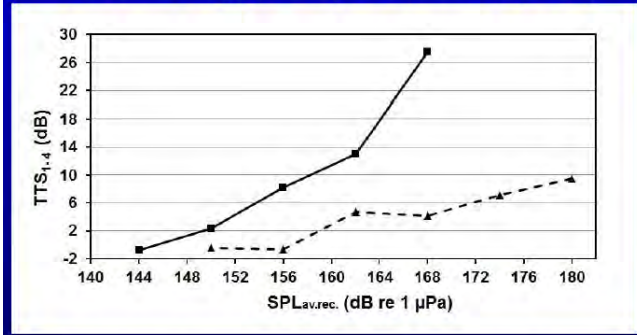
Sound types, signal durations, duty cycles determined by anthropogenic underwater sounds

26

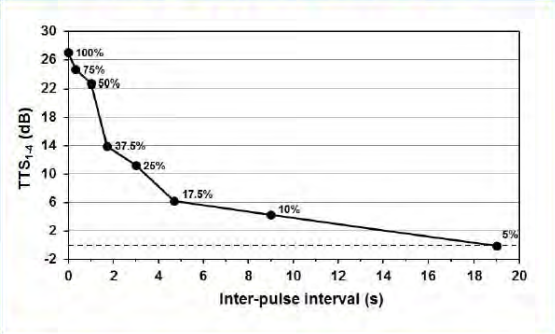
TTS due to intermittent sound in harbor porpoises

Naval LFAS: 1 s, 1-2 kHz up-sweep. Several duty cycles

Solid line: duty cycle 100%
Dashed line: duty cycle 10% (sound duration 1 s, IPI 9 s)



Sound duration 1-s
SPL: 168 dB re 1 µPa; exposure duration: 60 min.



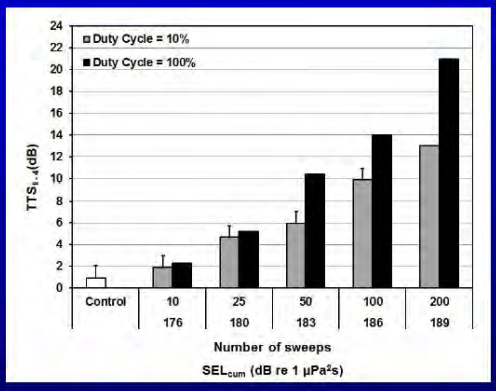
Kastelein, R.A., Hoek, L., Gransier, R., Rambags, M., and Claeys, N. (2014). "Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbor porpoise hearing," J. Acoust. Soc. Am. 136, 412-422. DOI: http://dx.doi.org/10.1121/1.4883596.

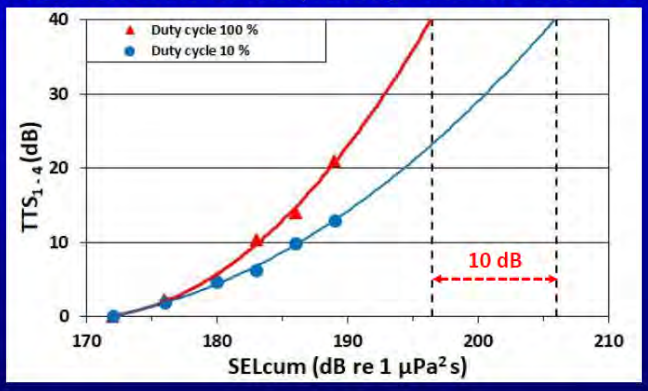
27

TTS due to intermittent sound in harbor porpoises

Naval MFAS: 1-s, 6-7 kHz down-sweeps, SPL 166 dB re 1 µPa, duty cycles 10% & 100%.
At 10% DC: IPI 9 s.

Estimation of PTS onset SELcum (assuming PTS occurs around 40 dB TTS)





Kastelein, R. A., Gransier, R., Schop, J., and Hoek, L. (2015). "Effect of intermittent and continuous 6-7 kHz sonar sweep exposures on harbor porpoise (*Phocoena phocoena*) hearing," J. Acoust. Soc. Am. 137, 1623-1633. DOI: 10.1121/1.4916590

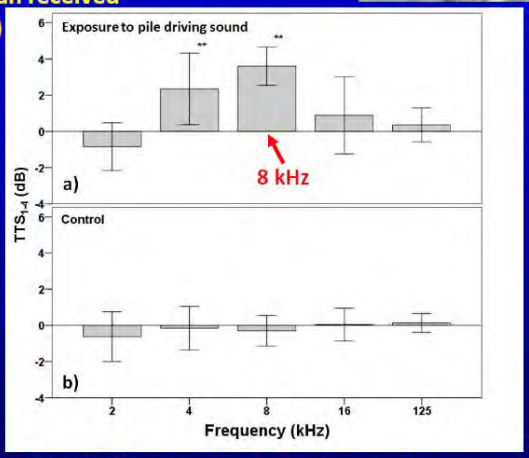
28

TTS due to intermittent sound in harbor porpoises

Impact pile driving: sound duration 124 ms, rate 2760 strikes/h, inter-pulse interval 1.3 s, duty cycle ~9.5%, 60 min, mean received SELss of 146 dB re 1 µPa² s (SELcum: 180 dB re 1 µPa² s)

Goal: determine the most affected hearing frequency

Recorded 100 m from the pile

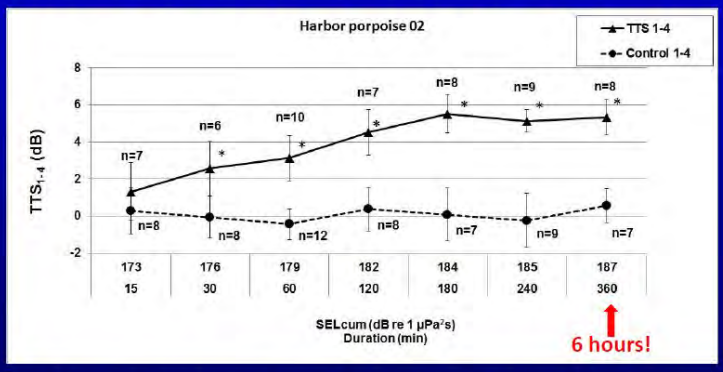


Kastelein, R. A., Gransier, R., Marijt, M. A.T., and Hoek, L. (2015). "Hearing frequencies of a harbor porpoise (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds," J. Acoust. Soc. Am. 137, 556–564, DOI: 10.1121/1.4906261.

29

TTS due to intermittent sound in harbor porpoises

Impact pile driving: pulse duration 124 ms, rate 2760 strikes/h, inter-pulse interval 1.3 s, duty cycle ~9.5%, SELss 145 dB re 1µPa²s, exposure duration: 15-360 min (SELcum: 173-187 dB re 1µPa²s). TTS measured at 8 kHz.



Kastelein, R.A., Helder-Hoek, L., Covi, J., and Gransier, R. (2016). "Pile driving playback sounds and temporary threshold shift in harbor porpoises (*Phocoena phocoena*): Effect of exposure duration," J. Acoust. Soc. Am. Am. 139, 2842-2851. http://dx.doi.org/10.1121/1.4948571.

30

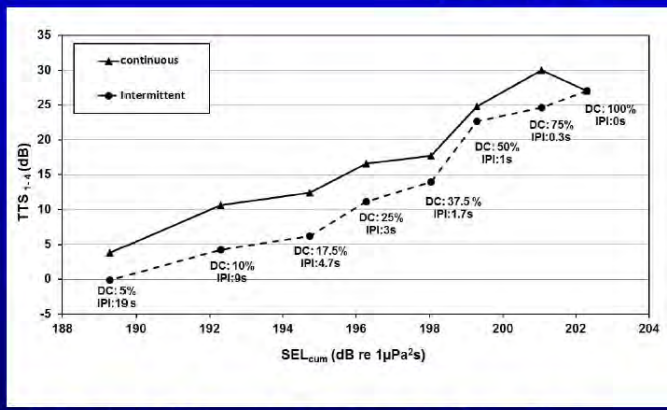
TTS due to intermittent sound in harbor porpoises

LFAS: 1-2 kHz down-sweeps of 1 s,

60-minute sequences of intermittent sounds, inter-pulse intervals (IPI) ranging from no interval to a 19 s interval, resulting in duty cycles (DC) ranging from 5 to 100 %.

Continuous sounds of variable length (1.5-60 minutes; 100% duty cycle).

Continuous and intermittent conditions are paired as eight exposure parameter combinations, which contain variable numbers of sounds (1 s sweeps) resulting in the same cumulative sound exposure levels (SELcum).
Mean exposure SPL: 168 dB re 1 µPa.

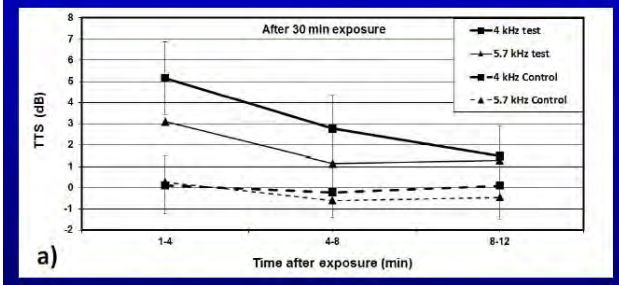


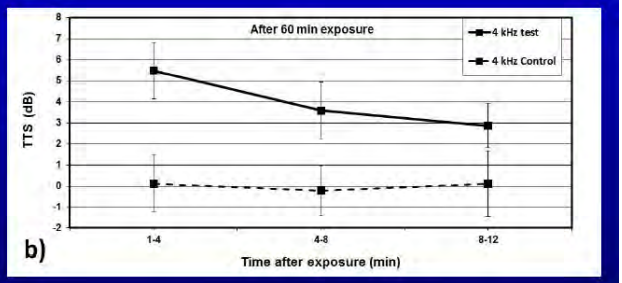
Kastelein, R.A., Hoek, L., and Gransier, R. (2016) The Cumulative Effects of Exposure to Continuous and Intermittent Sounds on Temporary Hearing Threshold Shifts Induced in a Harbor Porpoise (*Phocoena phocoena*). In: The Effects of Noise on Aquatic Life II, Advances in Experimental Medicine and Biology 875, Springer Science+Business Media New York 2016 763 (Eds. A.N. Popper, A. Hawkins), 523-528. DOI 10.1007/978-1-4939-2981-8_93.

31

TTS due to intermittent sound in harbor porpoises

53-C Naval sonar (3.5-4.1 kHz), sound duration 1600 ms, IPI: 60 ms. Duty cycle: 96%
SPL: 142 dB re 1µPa



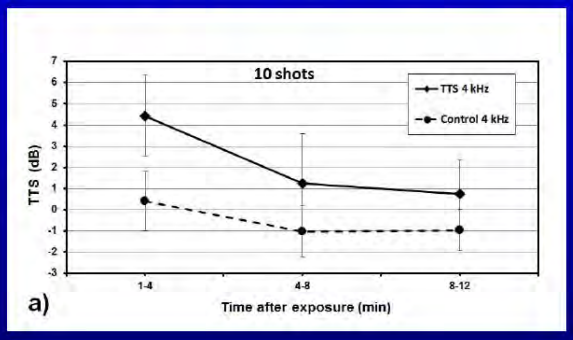


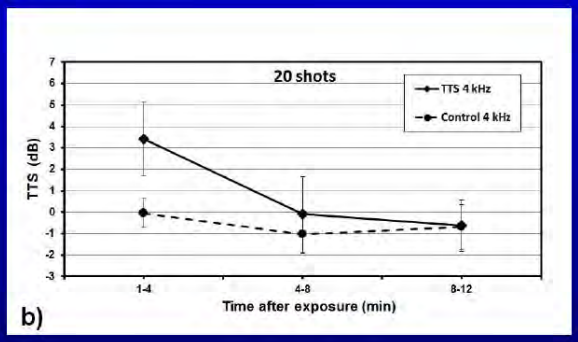
Kastelein, R.A., Helder-Hoek, L. and Van de Voorde, S. (2017). "Effects of exposure to 53-C sonar playback sounds (3.5-4.1 kHz) on harbor porpoise (*Phocoena phocoena*) hearing," J. Acoust. Soc. Am. 142, 1965–1975. https://doi.org/10.1121/1.5005613.

32

TTS due to intermittent sound in harbor porpoises

Airguns: SELss 175 dB re 1 µPa²s. 10 and 20 consecutive shots,
SELcum: 188 & 191 dB re 1 µPa²s, IPI: 17 s. TTS measured at 4 kHz



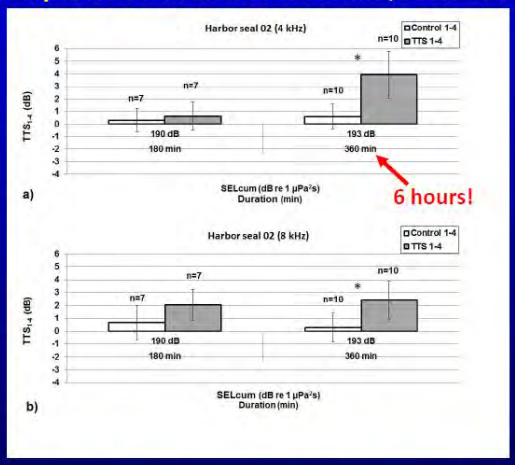


Kastelein, R.A., Helder-Hoek, L., Van de Voorde, S., von Benda-Beckmann, A.M., Lam, F-P. A., Jansen, E., de Jong, C.A.F., and Ainslie, M.A. (2017). "Temporary hearing threshold shift in a harbor porpoise (*Phocoena phocoena*) after exposure to multiple airgun sounds," J. Acoust. Soc. Am. 142, 2430-2442. DOI: 10.1121/1.5007720.

33

TTS due to intermittent sound in harbor seals

Impact pile driving: pulse duration: 127 ms, 2760 strikes per h, IPI: 1.3 s, duty cycle: 9.5%, SELss: 151dB re 1 µPa²s. Exposure durations 180 & 360 min, SELcum: 190 & 193 dB re 1 µPa²s

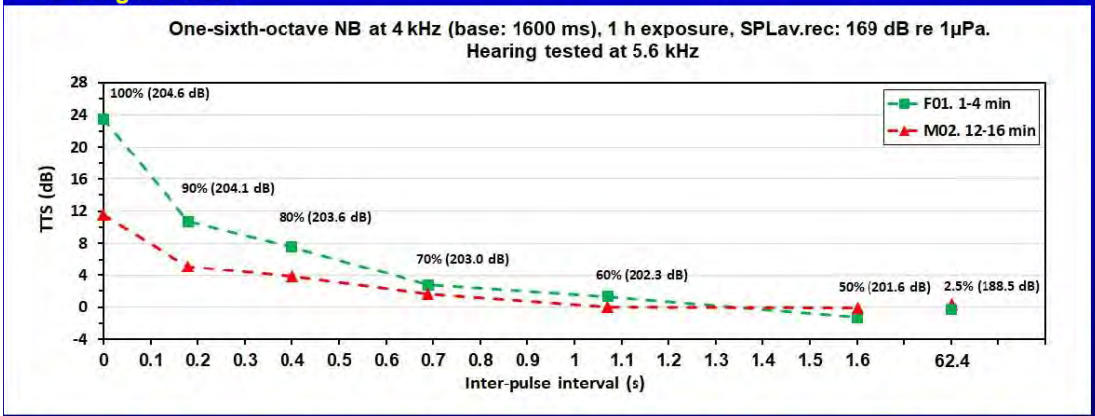


Kastelein, R.A., Hoek, L., Kommeren, A., Covi, J., and Gransier, R. (2018). "Effect of pile driving sounds on harbor seals (*Phoca vitulina*) hearing," J. Acoust. Soc. 143, 3583–3594. DOI: 10.1121/1.5040493

34

TTS in California sea lions due to intermittent sound

NB at 4 kHz: sound duration: 1600 ms, SPL: 169 dB re 1µPa. Exposure 60 min. Hearing at 5.6 kHz

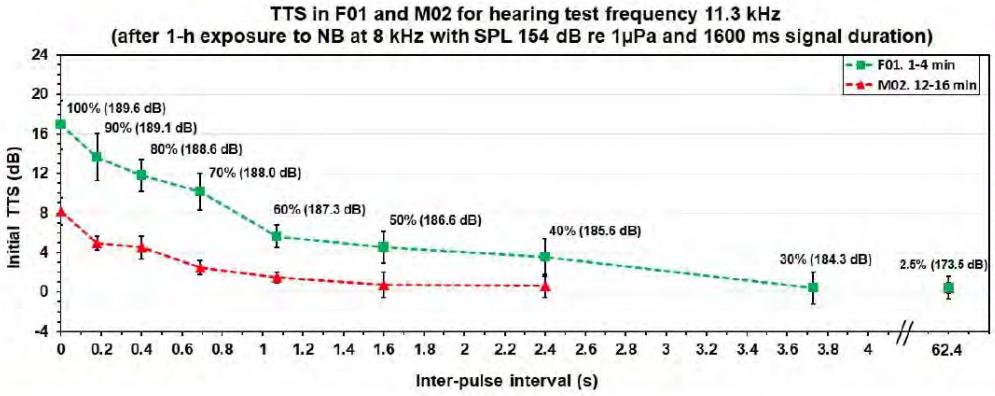


Kastelein, R.A., Helder-Hoek, L., Defillet, L.N., Huijser, L. A. E., Terhune, J. M. , and Gransier, R. (2021) Temporary hearing threshold shift in California sea lions (*Zalophus californianus*) due to one-sixth-octave noise bands centered at 2 and 4 kHz: effect of duty cycle and testing the equal-energy hypothesis. Aquatic Mammals, 47(4), 394-418, DOI 10.1578/AM.47.4.2021.394

35

TTS in California sea lions due to intermittent sound

NB at 8 kHz: sound duration: 1600 ms, SPL: 154 dB re 1µPa. Exposure 60 min.
Hearing at 11.3 kHz



Kastelein, R.A., Helder-Hoek, L., Defillet, L.N., Kuiphof, F., Huijser, L.A.E., and Terhune, J.M. (2022) Temporary hearing threshold shift in California sea lions (Zalophus californianus) due to one-sixth-octave noise bands centered at 8 and 16 kHz: Effect of duty cycle and testing the equal-energy hypothesis. Aquatic Mammals, 48(1), 36-58, DOI 10.1578/AM.48.1.2022.36

36

C-3. Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts (Dorian Houser)

Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts

DORIAN S. HOUSER
NATIONAL MARINE MAMMAL FOUNDATION

Current approaches (SOST agency funded)

- Auditory evoked potential methods
  - Minke whale hearing project
- Behavioral observation audiometry
  - Humpback whale behavioral response project
- Anatomical modeling
  - Bone conduction pathways/Cochlear mapping

Auditory evoked potential methods

- Pros
  - Direct measure of auditory system function
  - Determine frequency range of hearing
  - Obtain AEP thresholds
  - Potential application to calves and other small species
- Cons
  - Expensive
  - Greatest risk to animals
  - Lower limits of utility remain unknown
  - AEP thresholds overestimate behavioral thresholds
  - Limited number of people with capability

ABR tags

- Developing versions are modified Dtags
- Can be placed without needing to capture

Issues

- Tag placement is critical
- Needs to address how sound source is time-synchronized to tag
  - Onboard source has physical limitations to transducer (frequency limits)
  - External source needs to control for animal location and orientation (received level)
  - Needs to address brain-to-body mass ratio issue

Behavioral observation audiometry

- Pros
  - Non-invasive, low risk to animals
  - Methods don't limit frequencies that can be tested
- Cons
  - Requires lots of subjects
  - Masking might be an issue
  - Other factors may contribute to responsiveness

Anatomical modeling

- Pros
  - Can produce an audiometric function
  - No risk to animals
- Cons
  - Freshness of material is a factor; usually dependent on stranding events
  - Many free parameters in the models
  - Should be validated

How to address TTS in mysticete whales

- Surrogates
  - Difficulty in holding and handling mysticetes makes most exposure/test methods improbable
- Direct measures
  - Small, capturable whales might be usable as subjects (minke)
  - AEP methods can be used to assess I/O functions pre-/post-exposure
  - Challenges
    - Response of animal to exposure
    - Techniques need refining
      - Having sufficient amplitude/duration to obtain a measurable response
      - Subcutaneous electrodes might be of benefit
    - Permits might be an issue

Appendix D: Presentations by International Regulators

D-1. United States Partners in Management of Underwater Noise (Juliette Lee, Jolie Harrison, Tiffini Brookens)

United States Partners in Management of Underwater Noise

Our agencies work together to explore and manage ocean noise in US waters

BOEM is responsible for overseeing the management of the US Outer Continental Shelf's energy, mineral, and geological resources in an environmentally and economically responsible way.

NOAA's mission is to understand and predict changes in climate, weather, ocean and coasts; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources.

The Marine Mammal Commission provides independent, science-based oversight of domestic and international policies and programs that address human impacts on marine mammals and their environment.

BOEM's Challenges

Evidence Gaps

- Noise produced during installation of floating wind anchors.
- Noise produced from Dynamic Positioning Systems (DPS)
- Exposure to complex noise
- Cumulative effects
- Low-frequency cetaceans as high concerns
- Noise in the deep sea

Noise Management Issues

- Noise reduction during seismic surveys
- Noise abatement for pile driving
- Species-specific statutes
- Incentives

ESOMM 2024

NOAA's Challenges

Noise Management Issues

- Supporting and incentivizing quieting and noise abatement methods (primarily vessels, airguns, and pile driving). [*world-wide need to majorly reduce impacts*]
- Updating Behavioral Disturbance Criteria. [*specific NOAA regulatory tool needed*]
- Better incorporating existing data on sound, marine mammal impacts, and mitigation into risk assessment and management (especially for cumulative impacts). [*needed throughout the US Federal government*]

Associated Data Gaps

- Sound verification measurements and continuing engineering support for alternative quieter sources and NA methods.
- Select exposure/response data (e.g., pinnipeds, distance, pile driving).
- Continue building understanding of how the temporal/spatial scale of disturbance and other factors specifically influence the probability and severity of impacts on reproduction, health, and survival of different taxa.

ESOMM 2024

The Marine Mammal Commission's Challenges

Research Gaps

- Audiograms and auditory impacts for low-frequency cetaceans
- Auditory exposure to sounds with both impulsive and non-impulsive components
- Behavioral disturbance from exposure to various sound sources

Management Issues

- Determine the effectiveness of mitigation measures
- Develop better approaches for estimating repeated exposures
- Improve assessments of population-level impacts and cumulative effects

ESOMM 2024

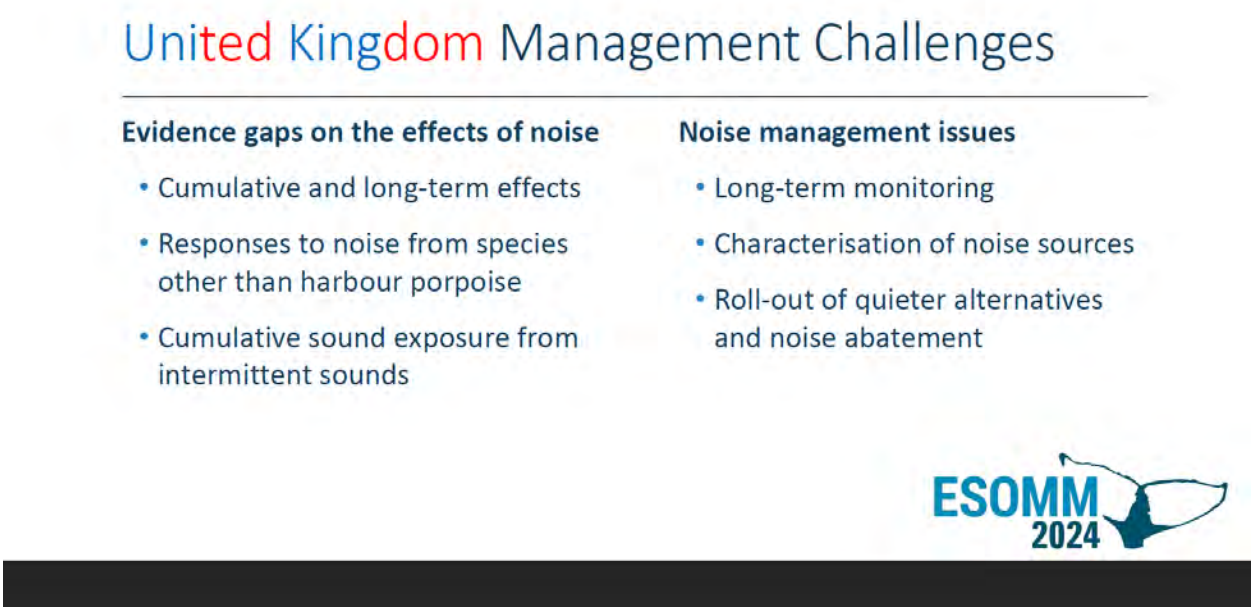
United States

Bureau of Ocean Energy Management
Juliette.Lee@boem.gov | boem.gov

National Oceanic and Atmospheric Administration
Jolie.Harrison@noaa.gov | noaa.gov

Marine Mammal Commission
TBrookens@mmc.gov | mmc.gov

D-2. United Kingdom Management Challenges (Sarah Canning for Sónia Mendes)



D-3. Challenges on Noise Regulation and Environmental Compliance in Germany (Klaus Lucke)

Challenges on Noise Regulation and Environmental Compliance in Germany

ESOMM 2024

Klaus Lucke

German Environment Agency

klaus.lucke@uba.de

German Partners in Management of Underwater Noise

German Environment Agency

- scientific oversight of (bio-)acoustic research;
- advancement of underwater noise regulation on national, regional and international level

Federal Maritime and Hydrographic Agency

- issues permits for installations of offshore windfarms
- regulates the emission of underwater noise in the German EEZ

German Federal Agency for Nature Conservation

- responsible for enforcement of nature conservation regulation
- planning processes related to protected areas

Germany – Management Challenges

Evidence Gaps

- Cumulative and long-term effects
- Population level consequences
- Crew Transport Vessels – Dynamic Positioning Systems
- Ultrasonic antifouling systems
- Deep sea (mining) noise

Noise Management Issues

- Compliance in the light of technological development:
  Noise abatement for XXL-pile driving
- Behavioural noise criteria – development, implementation, monitoring (LOBE criteria)
- Harmonization on national, regional and international level

DOSITS
Regulator/Decision Maker Needs Assessments

The DOSITS project surveyed the international decision maker community in 2014, 2015, 2017, 2019, 2021, and 2022.

Highest need topics for peer-reviewed research (accumulated data):

- Potential impacts of underwater sound at the individual and/or population level
- Long-term effects of noise on marine animals/Cumulative effects of sound exposure
- Potential physical effects of underwater sound
- Potential behavioral effects of underwater sound
- Effective mitigation to reduce potential effects

For more information, please contact:
Gail Scowcroft
<gailscow@uri.edu>

D-4. Netherlands Management Challenges (Niels Kinneging & Martine Graafland)

Netherlands Management Challenges

Overview

- Increase in human activities on the North Sea
  - Development offshore wind to meet climate change challenges
- Natural habitat types, species habitats and species, should be protected
  - European Union regulations, OSPAR
  - Ecosystem approach
  - Focus on protecting populations (more than individual animals)
- Knowledge gap on (cumulative) impact on marine mammals

ESOMM 2024

ESOMM 2024

The Netherlands

Rijkswaterstaat

Martine Graafland, Verna de Groes, Niels Kinneging

Martine.Graafland@rws.nl

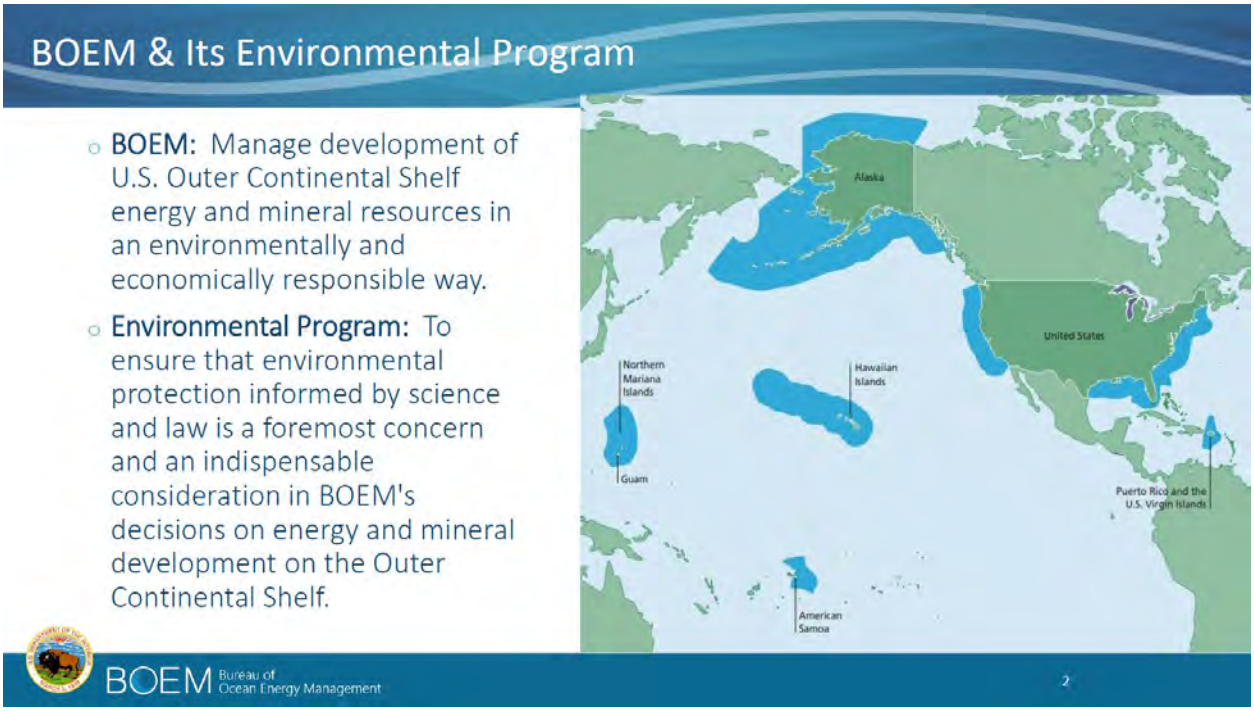
v.degroes@mininv.nl

Niels.Kinneging@rws.nl

https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/offshore-wind-ecological programme-wozep/

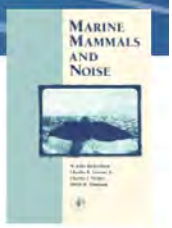
Appendix E: Presentations by International Funders

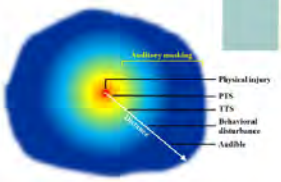
E-1. BOEM's Investment to Understand Noise Impacts on Marine Mammals (Shane Guan)



Studies to Understand Noise Impacts on Marine Mammals

- Long History of Funding and Research on Noise Impacts to Marine Mammals
  - First government agency to fund research on industrial noise impacts to marine mammals (starting late 1970s)
  - Initial marine mammal acoustic injury & behavioral criteria
  - Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ) & other passive acoustic monitoring of marine mammals in the Arctic (collaboration with the National Marine Mammal Laboratory)
  - Sperm Whale Seismic Studies in Gulf of Mexico (2002-2005)
  - Behavioral Response of Australian Humpback Whales to Seismic Surveys (2011-2017, co-found with JIP)





Center for Marine Acoustics & BOEM Acoustics Science Strategy

CMA Functions

Modeling. Build models that address needs & drive improvements.

Knowledge. Track emerging science & apply new risk assessment methods.

Policy. Address key policy & management improvements.

Messaging. Improve stakeholder understanding of actual risks.

Strategy. 6-year planning. Adapt based on performance & emerging information.

Partnerships. Develop relationships with organizations that advance shared goals.

BOEM Acoustics Science Strategy

- A comprehensive overview of BOEM's acoustic information needs
- With an eye on emerging topics that need to be addressed over the next 1-3 years, as well as long-term view of acoustics related science needs
- Updated annually with inputs from BOEM's programs and regions

ESP ENVIRONMENTAL STUDIES PROGRAM

Funded Ongoing Studies

- **Atlantic PAM Network:** A collaborative effort with multiple partners to establish and maintain a PAM network in the Atlantic OWAs to monitor baleen whales (RWSC & NEFSC, 2024-2029)
- **PAM for whales off MA & RI OWAs:** A pilot study for Atlantic PAM Network (LGL, 2022-2025)
- **North Atlantic right whale acoustic behavior:** Investigate NARW acoustic behavior, in particular, less known vocal cues in the mid-Atlantic region (Duke U., 2023-2025)
- **Algorithm development:** Developing an algorithm that incorporates PAMGuard with the Tethys Passive Acoustic Data Metadata System (Scripps & St. Andrews U., 2022-2024)

BOEM Bureau of Ocean Energy Management

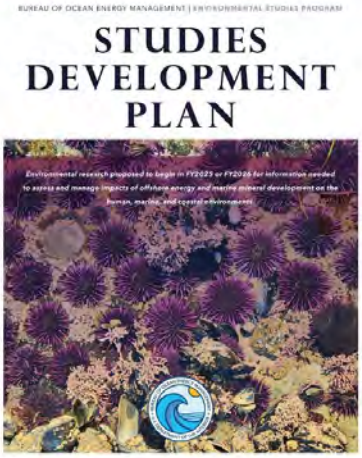
Funded Ongoing Studies

- **Low-frequency cetacean hearing:** A collaborative effect with ONR, LMR, & MMC to investigate low-frequency hearing in baleen whales (NMMF & UCSD, 2019-2024)
- **Low-frequency hearing in pinnipeds:** Investigate low-frequency hearing of bearded seal and California sea lion at frequencies 40-200 Hz (UC Santa Cruz, 2022-2025).
- **Marine vibroseis BRS study:** Co-fund with JIP to investigate behavioral responses of baleen whales from marine vibroseis sound exposure off California (SEA, 2024-2025)
- **Risk Assessment Framework:** Developing a quantitative assessment tool for environmental impacts analyses. (SEA, 2023-2027)

BOEM Bureau of Ocean Energy Management

FY2025 Studies Development Plan

- Applying distributed acoustic sensing technology to monitor large whales at Atlantic offshore wind areas
- Marine mammal hearing temporary threshold shift and auditory recovery from complex sound exposure
- Very low-frequency hearing in bearded seals
- All impacts are not equal: Artificial intelligence approaches for understanding impacts of BOEM permitted activities on sperm whale vocal clans
- Sound source characterization of dynamic positioning systems: Field verification



https://www.boem.gov/sites/default/files/documents/environment/environmental-studies/SDP_2025-2026.pdf

BOEM Bureau of Ocean Energy Management

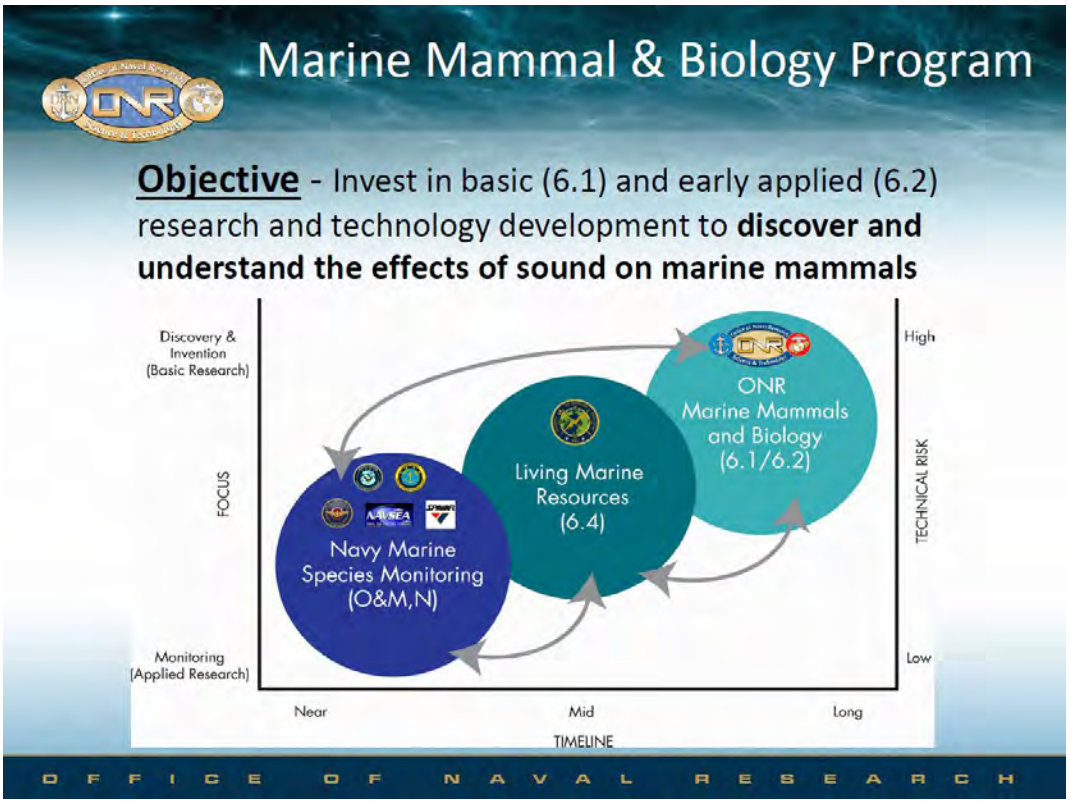
Partnerships

50 years of environmental science & research partnering and leveraging resources

Subcommittee on Ocean Science & Technology Interagency Working Group on Ocean Partnerships

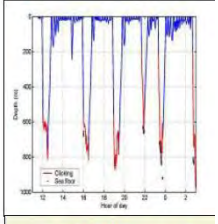
BOEM Bureau of Ocean Energy Management

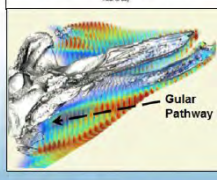
E-2. ONR Investment and Research Priorities (Michael Weise & Sarah Weiss)



Marine Mammal & Biology Program

1) Monitoring & Detection *(28)*
   - Environmental DNA *(10)*
2) Integrated Ecosystem Research *(18)*
   - Sensor and Tag Development *(8)*
3) Models & Databases for Decision Making *(5)*
4) Effects of Sound on Marine Life *(36)*
   - Behavioral Response Studies (BRS) *(6)*
   - Hearing (large whale only) (2)
   - Diving Physiology *(8)*
   - Stress Physiology *(5)*
   - Population Consequences of Disturbance (PCOD) *(15)*





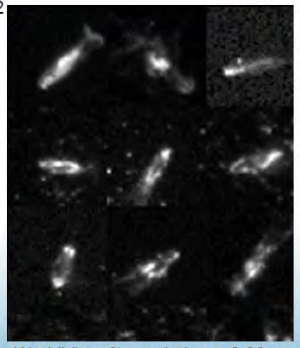
OFFICE OF NAVAL RESEARCH

Monitoring & Detection

- Passive Acoustic Monitoring
  - Long-endurance Argos floats
  - Low-cost arrays (LMR)
  - *Distributed Acoustic Sensing
  - *DCLDE
- *Whales from Space
- Thermal IR (LMR)

WHOI DMON2
Slocum glider

WHOI Thermal IR system



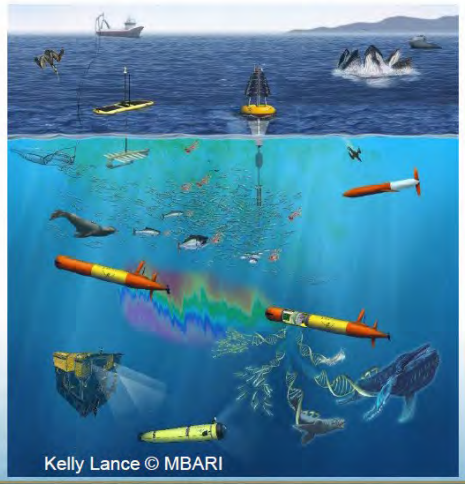
WorldView-3, resolution = 0.36m

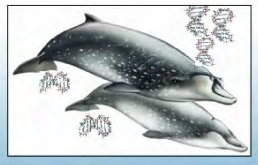
OFFICE OF NAVAL RESEARCH

Monitoring & Detection

Marine eDNA

- Powerful new tool to discover, map, monitor and manage marine life
- Provides a survey of all life from microbes to whales.
- Develop scalable, autonomous 'genomic weather stations' to monitor marine life in real-time and at basin scales
- TRLs – 9 (lab-based); 4 (autonomous)



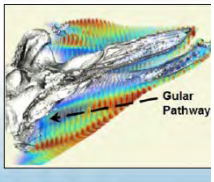


Hearing

White House Office of Science and Technology Policy (OSTP), Subcommittee on Ocean Science & Technology (SOST), Interagency Working Group - Ocean Sound & Marine Life (OSML)

Development of Audiograms for Mysticetes

- Minke Whale AEP Hearing – PI, Houser
- Humpback BRS Thresholds – PI, Dunlop
- Gray Whale FEM – PI, Cranford



Behavior Response Studies

Field Site / Stimuli / Species

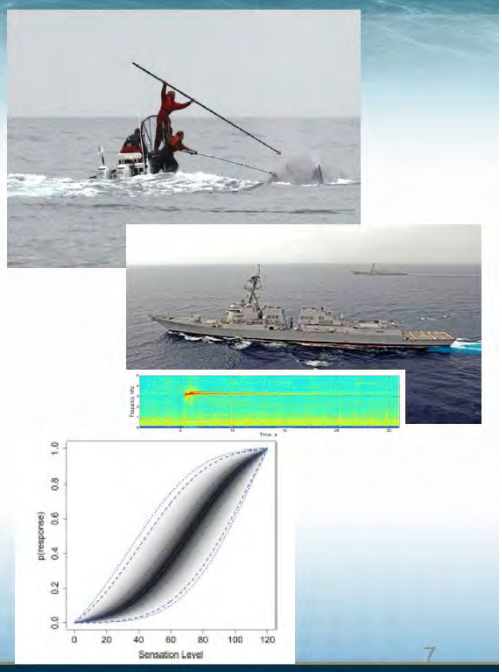
- AUTEC 2007-2008
- 3S - 2006-2010
- Mediterranean 2009
- SOCAL BRS 2010-2016
- 3S^2 2011-2014, 3S^3 2015-2016

Enabling technology

- Acoustic Tags (i.e. Dtag, SMRT)
- Analytical tools (i.e. MOCHA, ^2)
- Growing Capacity

New Approaches

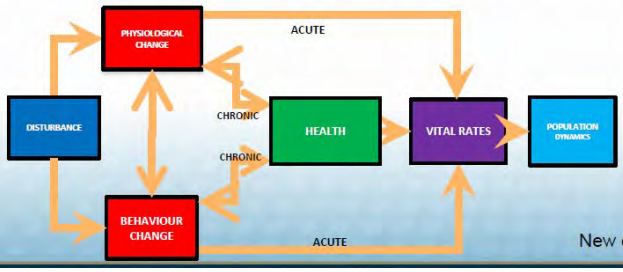
- Tagless BRS, Opportunistic, Observational (i.e. Acoustics)
- *Linking to health and PCOD
- *Review (i.e. BREWW 2015)



ONR Effects of Sounds

PCOD / Cumulative Effects

- Conceptual model development
- Quantitative model & tool development
- Interim Applications - Expert Elicitation (PCOD–lite)
- Comparative populations (SOCAL/Azores/Guad; AUTEC/Abacco)
- Developing metrics (i.e. body condition; health scores)
- Technology development (tags – buoyancy, draw blood)



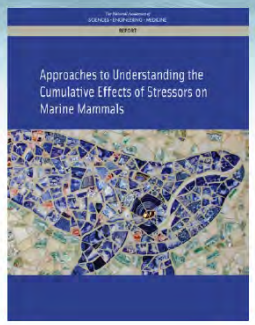
New et al. 2013, *PLoS One*

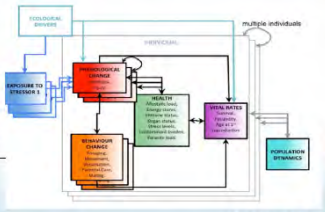
ONR Effects of Sounds

PCOD / Cumulative Effects

SERDP RCSON-20-C2: Cumulative Effects of Multiple Stressors on Marine Mammals

- **SERDP Multi-Stressors Working Group – funded by SERDP/ONR, executed by ONR MMB**
  Weise / ONR; Tyack, Thomas, Harris / Univ of St Andrews
- **Towards an Understanding of the Cumulative Effects of Multiple Stressors on Marine Mammals (Tursiops, NARW case studies)**
  (RC20-C2-1097) – Tyack / Univ of St Andrews, NMMF, WHOI, New England Aquarium, Duke Univ, Chicago Zool. Society, SEA, NMFS
- **Assessment of the Cumulative Effects of Multiple Stressors on Marine Mammals– Elephant Seals as a Model System**
  (RC20-C2-1284) – Costa / UC Santa Cruz, Sonoma State Univ, MLML, USGS
- **Modelling baleen whale response to multiple stressors through replicate physiological sampling of gray whales**
  Torres / OSU (co-funded DOE)





NAS 2017

Internships for Equity and Inclusion

Cox, Savannah State University

- Need for strategies to ensure a diverse and innovative future STEM workforce in the USA
- 2nd phase project– Historically Black Colleges & Universities, Minority Serving Institutions
  - Paid academic year internships @ HBCU / MSI
  - Weekly cohort meetings
  - Mentor training at partner organizations
  - Paid summer internships at partner organizations
  - Conference travel

Research Priorities

- Monitoring & Detection
  - DCLDE, DAS, Whales from Space, eDNA
- BRS
  - Linking to health, PCOD, Cumulative Effects
  - Review State of the Science, ID needs
- PCOD / Cumulative Effects
  - Bioenergetics workshop – converge on models/assumptions
  - Technology development, health metrics (i.e. epigenetics, 'Omics)
- Cumulative Effects
  - Refine models, addit'l case studies, quantify/predict Interactions (Additive, Synergistic, Antagonistic)
- Education – HBCU/MSI Internship Program
  - HBCU / MSI

Questions?

ONR MMB Program

http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology.aspx

E-3. Living Marine Resources RDT&E Program (Ben Colbert, Anu Kumar & Mandy Shoemaker)

INVESTMENT AREAS

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



3

HEARING RESEARCH OVERVIEW

- External scientific panel review of Current Status and Future of Underwater Hearing Research
- Underwater behavioral audiograms to study frequency dependent hearing sensitivity
  - Bottlenose dolphins, harbor porpoise, and killer whales
  - California sea lions, harbor seals, monk seals
- AEP based hearing research
  - ANSI standard on measuring AEP in cetaceans
  - Low-frequency AEP signal for testing large whale hearing
  - Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds
- Large whale hearing
  - Finite Element Modeling (Anatomical) for mysticetes – humpback
  - Partnered with SOST (ONR, BOEM, NMFS, MMC) to study large whale hearing
    - Minke whale – direct AEP testing
    - Humpback whale – behavioral response
    - Gray whale – anatomical model
- Perceived loudness of signals of differing duration – bottlenose dolphins, killer whales, California sea lion
- Auditory Masking – California sea lion, walrus, and ringed/bearded seal (in-air only)


4

TTS RESEARCH OVERVIEW

- Frequency dependent TTS onset
- TTS Growth and Recovery
- Signal duty cycle effect on TTS
- Equal-energy hypothesis (High SPL/short duration = low SPL/longer duration)
- Exposure duration effect on TTS

*Captive species studied: bottlenose dolphin, harbor porpoise, harbor seal, California sea lion

5

BEHAVIORAL RESPONSE RESEARCH OVERVIEW

- Behavioral Response Research and Evaluation Workshop (BRREW) (co-funded by ONR MMB, NOAA)
- Methods
  - Controlled Exposure Experiments (blue, fin, goose-beaked whale, sperm whales, killer whales)
  - Opportunistic/Coordinated Exposure Experiments (fin, goose-beaked whale)
  - Captive observations (harbor porpoise)
  - PAM on Navy ranges (Blainville's beaked whale)
- Sources
  - Simulated MFAS, operational Navy 53C sonar, helo-dipping sonar, continuous active sonar (CAS)
  - explosives
- Topics
  - Received level
  - Effects of range (distance from source)
  - Long duration exposures
  - Comparison of signal types (pulsed active sonar [PAS] vs. CAS)

6

HEARING/TTS RESEARCH FUTURE NEEDS

- Identify research topics to collaborate with other federal and international partners
  - Workshop to prioritize studies involving captive animal programs
  - Evaluation of further need to investigate large whale hearing
- Hearing and TTS research related to
  - Additional research on specific sources/signals (i.e SURTASS LFA, CAS, etc.)
  - Additional species or functional hearing groups
  - Additional topics related to masking effects (how will results be used in impact analysis?)
- Sea turtle TTS study

7

BEHAVIORAL RESPONSE RESEARCH FUTURE NEEDS

- Identify research topics to collaborate with other federal and international partners
  - Additional priority species/sources with overlapping interest
- SURTASS LFA Phase II BRS
  - Currently working out what source will be used
- Pinniped BRS (new in 2025)
  - Focus will be California sea lion and MFAS
- Sea turtle BRS?

8

PROGRAM OUTREACH

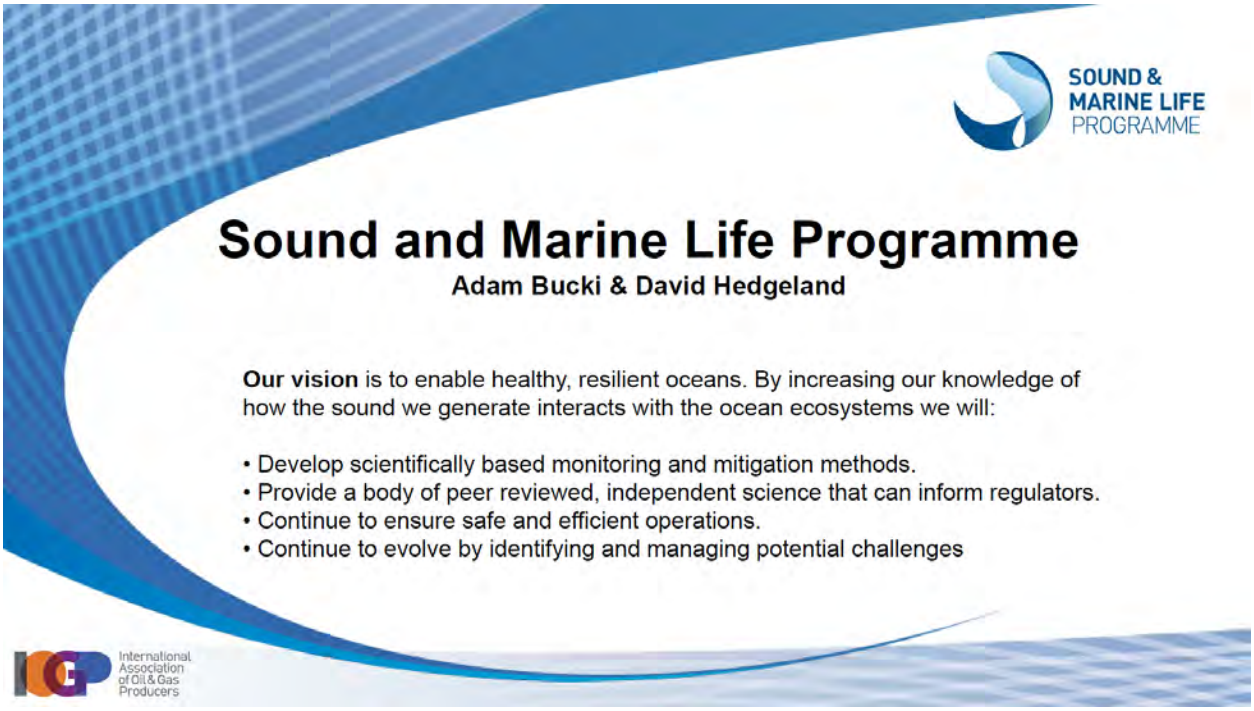
http://exwc.navfac.navy.mil/lmr

9

9

QUESTIONS?

E-4. Sound and Marine Life Programme (Adam Bucki & David Hedgeland)



Current Program

- **Low Visibility Marine Mammal Detection Methods**
  - **Why** – Low visibility time periods are a known mitigation gap and the inability to detect animals can limit 24 hour operations.
- **Behavioral Response of Whales to Marine Vibroseis**
  - **Why** – We need to understand what type of response, if any, animals have to this source so that regulatory frameworks and impact assessment methods can enable it's use.
- **Population Consequence of Disturbance (PCOD) use for Impact Assessment**
  - **Why** – Methods to assess population consequences of activities (particularly long term/cumulative effects) are not broadly accessible or adopted. Such tools will enable scientific-based prediction of long-term basin-wide impacts.
- **Mysticete Hearing – Improved Weighting Functions and Thresholds**
  - **Why** – Little is known and recent published thresholds lack the ground truth that exists for other, smaller species.
- **Continuous Versus Impulsive Sound Expert Workshops**
  - **Why** – An expert panel workshop series will aim to align the community on the knowledge gaps and the science needed to fill them. Workshops will set the stage for future Programme focus areas.

SOUND & MARINE LIFE PROGRAMME

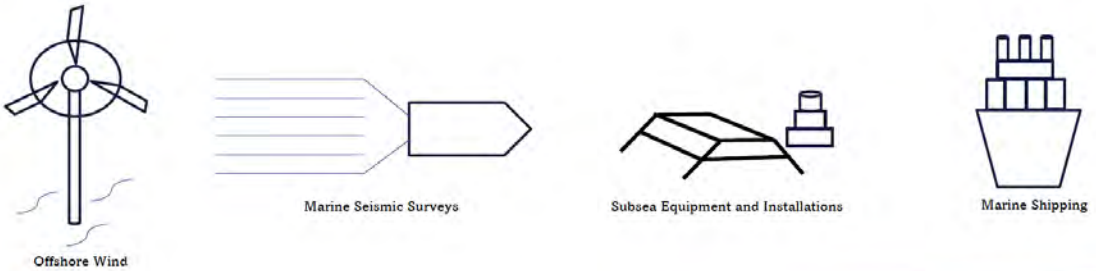
Isn't this a solved problem?

Although significant progress has been achieved by the JIP and other entities. Many important discussions have been enabled through the Programme and regulatory gaps and science gaps filled.

For example:

- PAMGuard software provides a standardized interface implementing PAM during geophysical surveys.
- Outcomes of numerous JIP supported studies provide inputs to scientific discussion that inform threshold criteria.

However, the challenges continue to evolve, with interest shifting from air gun sources to include other sources of anthropogenic sound but also the long term/population level/cumulative impacts of sound.



SOUND & MARINE LIFE PROGRAMME

The challenges continue to evolve...

Common Challenges:

- **Geophysical surveys are a focus for both Oil and Gas as well as offshore renewables.**
- **Alternative survey sources such as marine vibrators do exist, but science gaps still prevail. Regulatory acceptance and incentives are critical to enable implementation.**
- **Increasing attention impacts of sound at national and regional scales.**
- **Potential impacts of continuous sound is poorly understood.**
- **Methods to assess the cumulative effects of multiple operations on marine populations**

Marine Shipping

Subsea Equipment and Installations

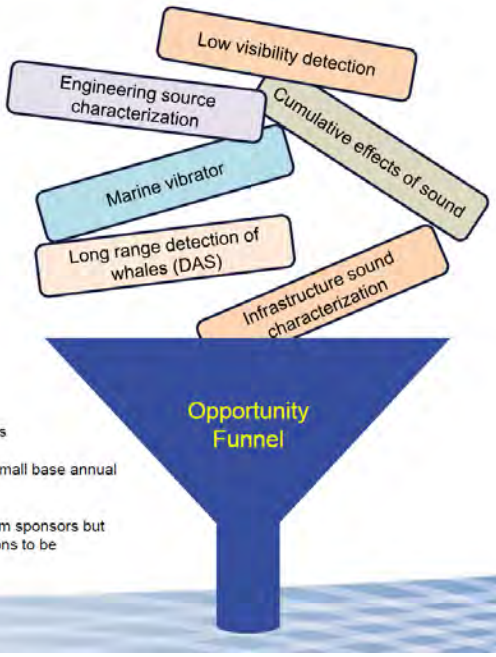
Marine Seismic Surveys

Offshore Wind

SOUND & MARINE LIFE PROGRAMME

Program Outlook

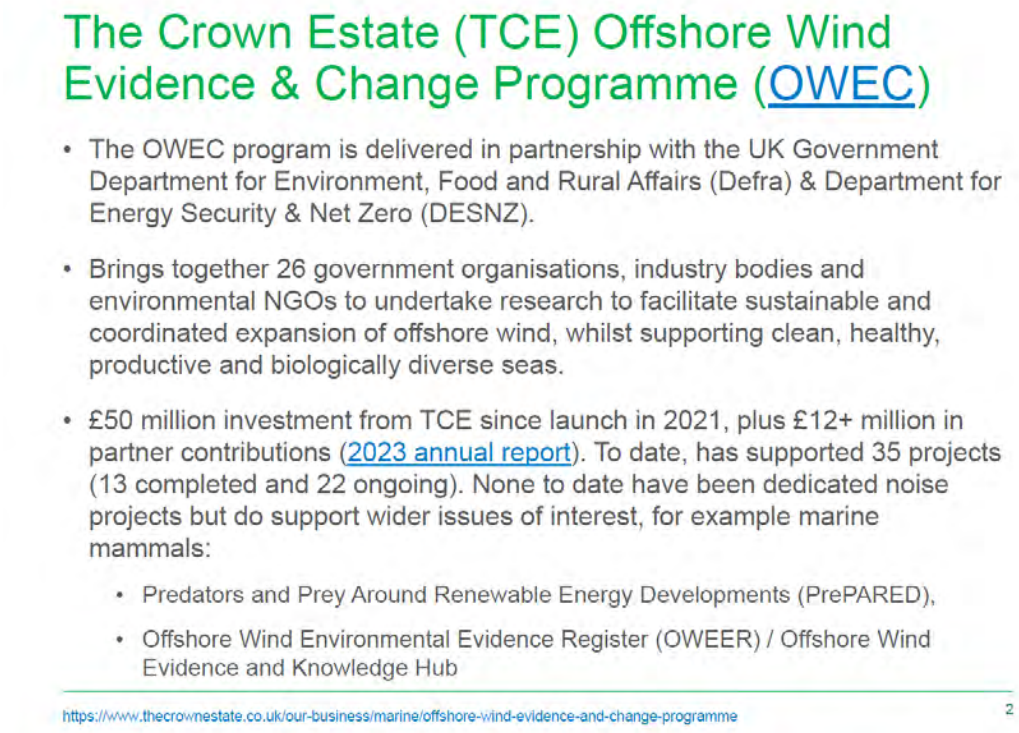
- Many topics in line with regulatory and operational needs but key limitations are funds and staff time
- Strengthening ties to advocacy groups and regulators to high-grade and identify highest priority projects and pool resources.
- Continue science programs but also ensure advocacy based on past projects is robust.



- Multi-million proposed projects from members
- Looking to partner/prioritize seriatim due to small base annual budgets.
- JIP structure allows for additional funding from sponsors but requires proposals and clear value propositions to be developed.

SOUND & MARINE LIFE PROGRAMME

E-5. UK Research Programmes to Understand Marine Mammal Acoustic Impacts (Sarah Canning)



Offshore Wind Environmental Evidence Register(OWEER)

- UK-wide register of offshore wind evidence gaps.
- Publishes high priority evidence gaps and recommends research themes to address consenting risks for offshore wind.
- High priority themes for marine mammals are:
  - Responses of marine mammals to operational wind turbines.
  - Causes, frequency of occurrence and consequences of PTS and disturbance.
  - Noise reduction and mitigation techniques.
  - Chronic (long-lasting) effects of noise and disturbance.
- Evidence gaps also includes:
  - Noise thresholds for disturbance of pinnipeds.
  - Better understanding of uncertainties in noise prediction modelling.
  - Noise produced by Floating Offshore Wind (construction & operation)

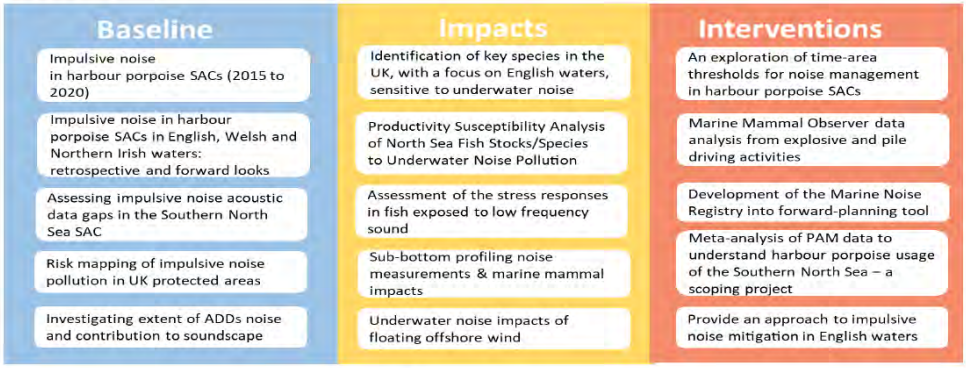
Offshore Energy Strategic Environment Assessment (OESEA) research program

- Managed by the UK Government Department for Energy Security & Net Zero (DESNZ).
- The Strategic Environmental Assessment (SEA) process considers the environmental implications of planned plan/programs. DESNZ have undertaken SEAs for offshore O&G and renewables licensing rounds since 1999.
- The OESEA research program has been part of the appraisal program since 1999; this identifies evidence gaps and commissions new research to improve the evidence base for undertaking strategic assessments and support activity specific consenting.
- Between 2010 and 2024 (April) have commission 59 projects (18 ongoing) and published 48 research reports, 67 peer reviewed papers and 3 PhDs. Ongoing noise related projects (April 2024):
  - Understanding sound generated during disposal of unexploded ordnance at sea.
  - NIRS tags to study physiological and energetic consequences of noise.

https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#offshore-energy-sea-research-programme

Offshore Wind Enabling Actions Programme (OWEAP)

- Three-year government-funded project undertaken by Department for Environment, Food and Rural Affairs (Defra).
- Work broken down into themes, one of which focussed on underwater noise.
- Culminated in the publication of 15 noise related projects and new policy development.



OWEAP publications 2021: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21308
OWEAP publications 2022: https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21304

5

Scottish Marine Energy Research (ScotMER) Programme

- Funded by Scottish Government, to improve evidence base around how offshore renewable energy developments may affect the environment.
- Facilitates collaboration between academia, industry statutory advisers, and non-government organizations; identifies evidence gaps and enable/fund targeted research.
- 27 publications since 2020 and 17 projects currently underway.
- Hold regular symposiums showcasing research (free to attend and now online)
- Previous projects include:
  - Developing marine mammal dynamic energy budget models.
  - a review of energy conversion factors in underwater radiated sound for piling.
- Current projects include:
  - PAM as a bioindicator, pilot study.
  - Methodology for combining digital aerial survey data and passive acoustic baseline data.
  - Salmonid tracking to inform spatial movements around offshore wind farms in the Moray Firth.

6

Collaborative > Offshore Wind Industry Council Pathways to Growth (P2G)

- The Offshore Wind Industry Council (OWIC) was established in May 2013 to drive the development of the offshore wind sector in the UK.
- Co-chaired by the Minister of State for DESNZ, and a government appointed industry co-chair. Brings Government & industry together to realise UK's renewable energy ambitions.
- P2G workstream focuses on identifying and addressing key environmental consenting challenges that will be a barrier to the UK meeting its renewable and net zero targets.
- Focus areas includes underwater noise and a need for guidance on managing noise in/around marine mammal protected areas (SACs) to have greater certainty thresholds won't be breached.
  - Current project > Underwater noise: coordination and conflict resolution
- 2025/2026 > TBC but will be focus on supporting adoption of evidence to inform underwater noise management

https://www.owic.org.uk/our-work/pathways-to-growth 7

Industry funded > Offshore Renewables Joint Industry Programmes (ORJIP)

Ocean Energy

- Programme sponsors include TCE, Marine Scotland & Welsh Government, TCE Scotland, Scottish Natural Heritage (now NatureScot), Natural Resources Wales.
- Pilot stage to establish programme, progress research and monitor projects.
- Consenting risks identified included:
  - Lack of available acoustic data from operational devices/arrays.
  - Knowledge of possible effects of underwater noise from construction of/operational arrays.

Ocean Wind

- Managed by Carbon Trust and sponsored by TCE, TCE Scotland and Marine Scotland with individual project developer funding.
- Stage 1 (2012 – 2018) projects included
  - Efficacy of ADDs
  - Impacts on fish from piling
- Stage 2 (2019 – 2023, option to 2025) projects include:
  - Reducing conservatism in underwater noise assessments (ReCon)
  - Range dependent nature of impulsive noise (RaDIN)

http://www.orjip.org.uk/ 8

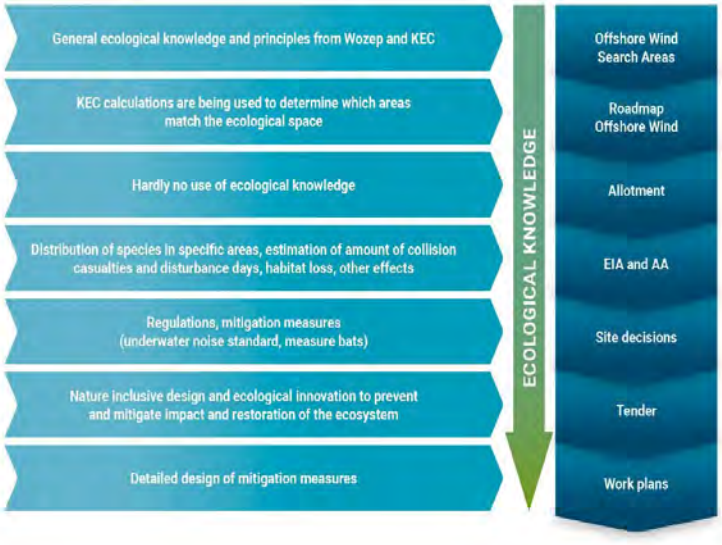
E-6. Wind at Sea Ecological Programme (Martine Graafland, Verna de Groes & Niels Kinneging)

The Dutch approach

- SEA, KEC, EIA, AA, application, Site decision ("permit") -> all by government
- Tender-criteria: government
- Tender-winner -> WFO

- So in the Netherlands most research programms governmental, (co)funded by government, or in tendercriteria (WFO)

Example: use of wozep/KEC knowledge in procedures



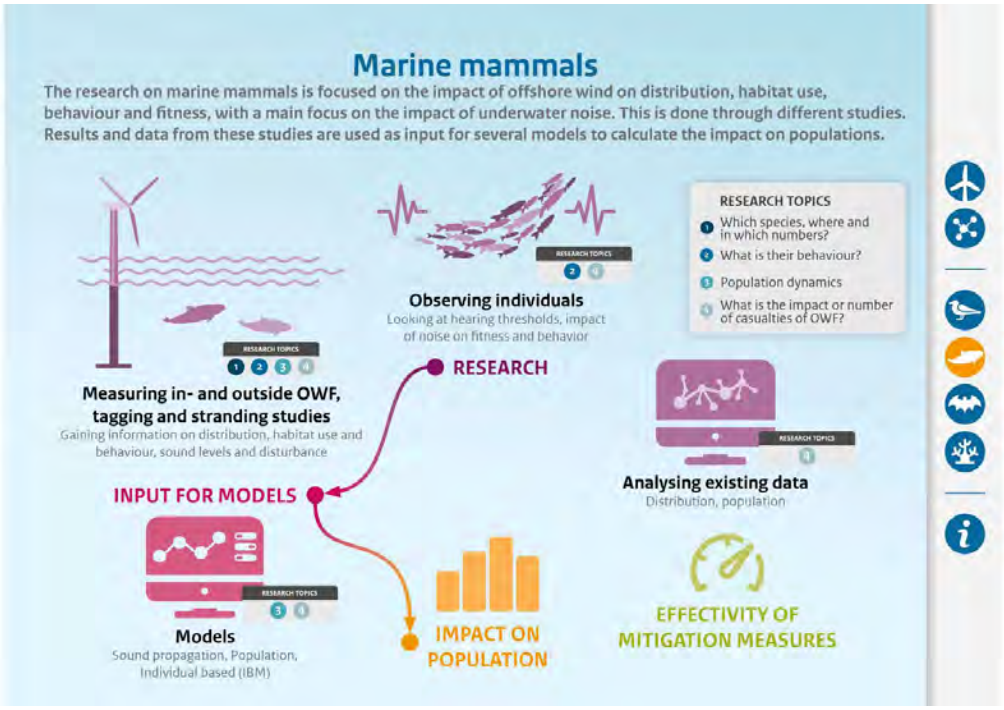
Wind at Sea Ecological Programme

- Ecological effects of offshore Wind energy
- Future effects of policy decisions now
- Effects on protected species

DUTCH GOVERNMENTAL OFFSHORE WIND ECOLOGICAL PROGRAMME

Wozep themes

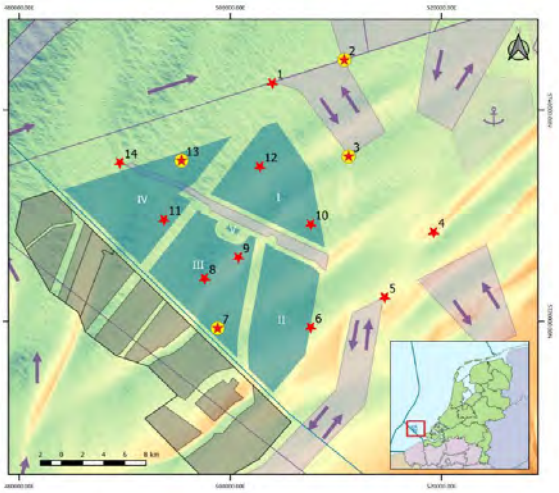
- Coastal and sea birds – collisions, habitat loss
- Migratory birds – collisions, barriers
- Bats – collisions during North Sea crossing
- Marine mammals – underwater noise, habitat suitability
- Ecosystem effects – large scale changes of the ecosystem
- Use of knowledge – Framework Ecology and Cumulation (KEC)

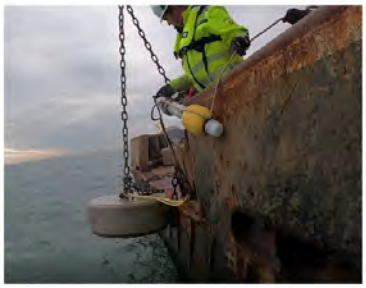


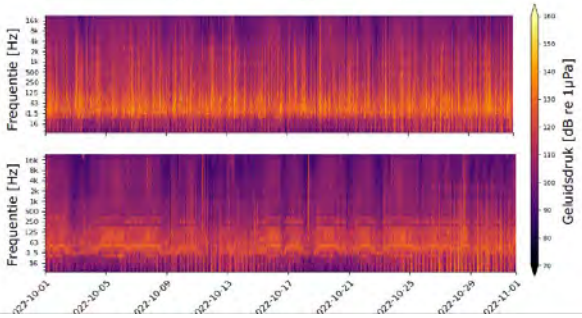
Marine mammals in Wozep

- Underwater noise
  - Direct effects (construction and operational)
  - Indirect effects (e.g. UXO clearance)
- Habitat suitability of wind farms
- Population studies

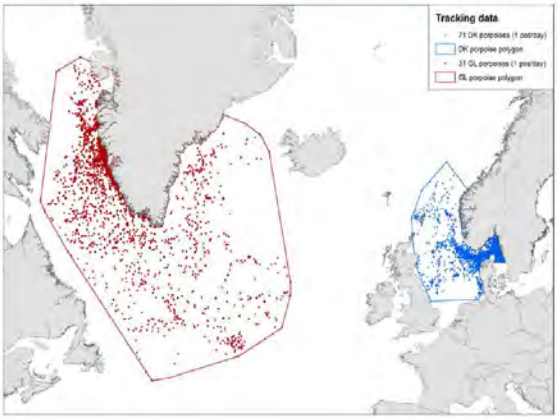
Passive Acoustic Monitoring (Borssele wind farm)



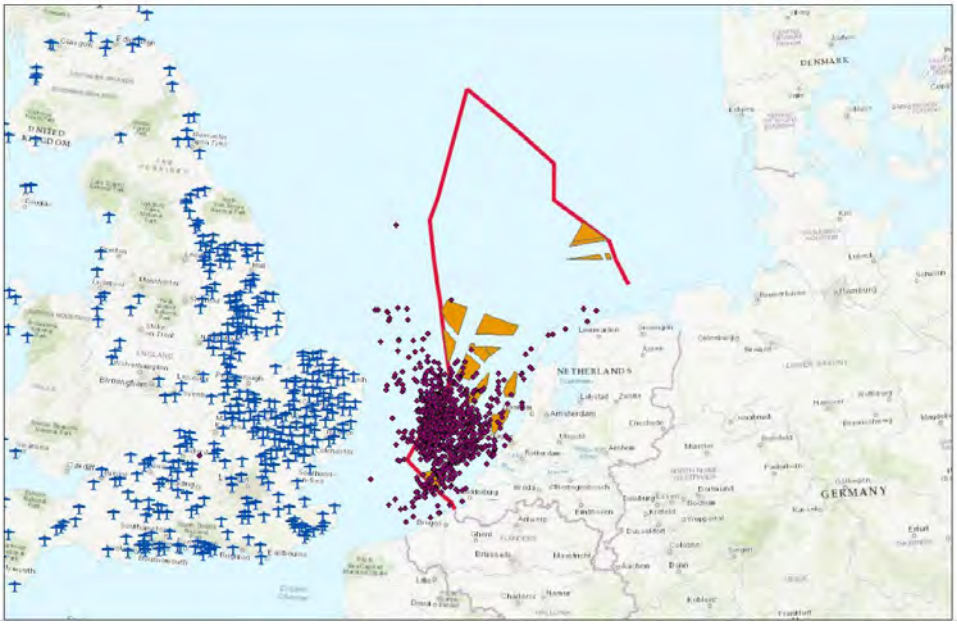




Porpoise tagging pilot (recently started)



Example UXO



11

Other programmes and projects regarding underwatersound/marine mammals

Monitoring

- Before application: site specific monitoring (RVO) -> under development, now mostly benthos, soil characteristics, etc
- MWTL/WOT (regular monitoring, governmental funding)
- International (SCANS)

Research Fundamental science

- MONS (Monitoring and Research on Nature enhancement and protection of Species)
- NWO calls -> University and research institutions (PhD, PostDoc) (co-funding, governmental and WFO/Builders)

Research Applied science

- TKI (governmental funding)
- NWO-calls (Technical University and research institutions) (co-funding, governmental and WFO/Builders)
- Tender-winners (WFO)

12

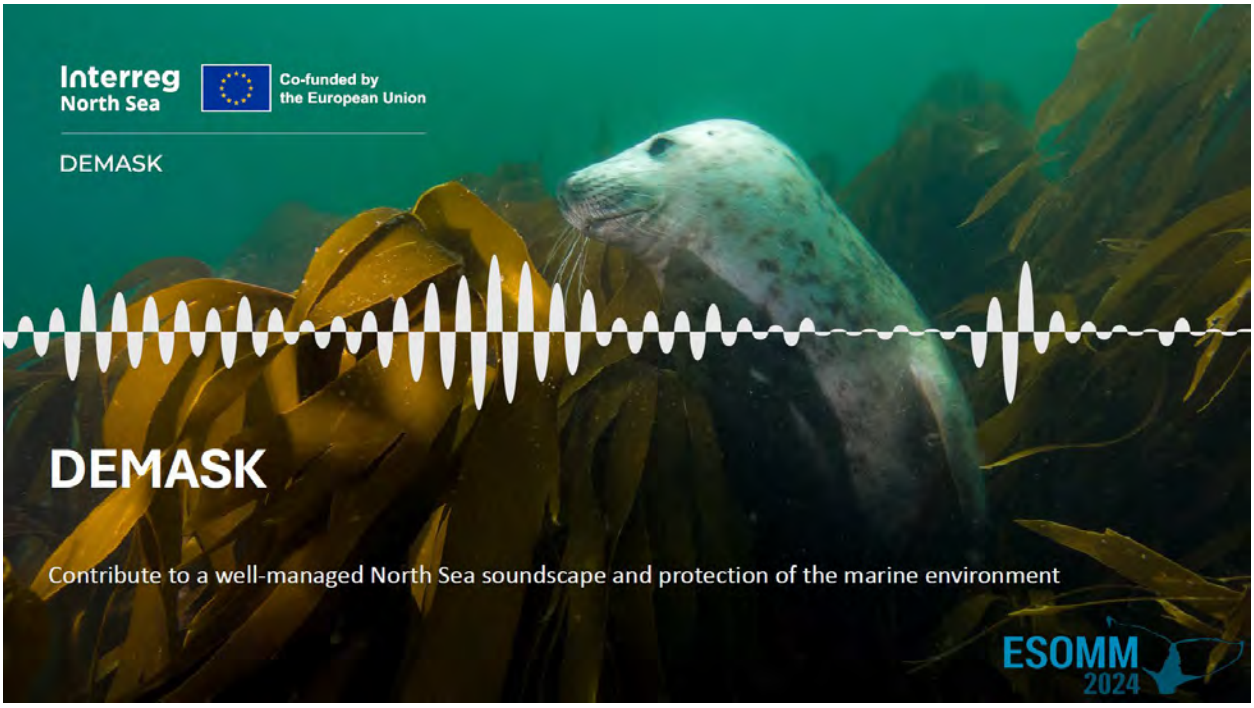
Funds by European Union

- LIFE+
- Interreg
- Horizon Europe
- European Maritime and Fisheries Fund

Interreg Co-funded by the European Union

Example CIBBRiNA on Bycatch

- Working together to minimise bycatch of Endangered, Threatened and Protected species in the North-East Atlantic, Baltic, and Mediterranean


Interreg
North Sea
Co-funded by
the European Union
DEMASK
DEMASK
Contribute to a well-managed North Sea soundscape and protection of the marine environment
ESOMM
2024

Appendix F: Workshop Summary Presentation

Workshop on Marine Mammal Noise Impact Research & Funding Priorities Report Out (Shane Guan, Sónia Mendes & Juliette Lee)

Agenda

- **Session 1: Open session**

  12:35-13:40 State-of-the-science presentations and discussion

  13:40-14:35 Management challenges presentations and discussion

- **Break**

  14:35-14:50

- **Session 2: Closed-door session without funding recipients**

  14:50-15:50 Presentations on investment and research priorities from a number of international funders

  15:50-16:30 Discussions on research/funding priorities & cost-sharing strategies

- **Adjourn**

  16:30

State-of-the-Science: Presentations

1. Assessment of Noise Impacts on Marine Mammals: Acoustic Criteria, Field Observations, Research and Mitigation Priorities (Southall, SEA & Nowacek, Duck U.)
   - Several recommendations on experimental studies, observations, & monitoring, and establishing behavioral effects criteria
2. Approaches to estimate cumulative sound exposure effects on hearing in a real-world scenarios (Ron Kastelein, SEAMARCO)
   - Pilot studies to test equal energy hypothesis using sound of same SPL and same SEL but different duty cycles.
3. Approaches to Develop Baleen Whale Audiograms and Recommendations on Establishing Baleen Whale Noise-induced Threshold Shifts (Dorian Houser, NMMF)
   - Pros and cons of different methods to investigate low-frequency cetacean hearing.
   - Challenges to study low-frequency cetacean hearing threshold shifts.

Regulatory Challenges: Evidence Gaps

Evidence Gaps	Country (Agency)
Cumulative & long-term effects	US (BOEM); UK (JNCC); Germany (BSH); The Netherlands (Rijkswaterstaat)
DPS & crew transport vessel noise	US (BOEM); Germany (BSH)
Noise in deep sea	US (BOEM); Germany (BSH)
Complex sound exposure	US (BOEM, MMC)
Low-frequency cetacean acoustics	US (BOEM, MMC)
Noise from floating wind anchor installation	US (BOEM)
Behavioral responses from multiple sources	US (MMC)
SSV & support for quieter sources	US (NOAA)
Select exposure/response data	US (NOAA)
Temporal/space scale of disturbances	US (NOAA)
Response from species besides harbor porpoise	UK (JNCC)
Population level consequence	Germany (BSH)
Ultrasonic antifouling system noise	Germany (BSH)

Regulatory Challenges: Noise Management Gaps

Noise Management Gaps	Country (Agency)
Quiet alternative and noise abatement	US (BOEM); UK (JNCC); Germany (BSH)
Behavioral criteria	US (NOAA); Germany (BSH)
Incentives	US (BOEM, NOAA)
Noise reduction during seismic surveys	US (BOEM)
Species-specific statutes	US (BOEM)
Mitigation effectiveness	US (MMC)
Estimate repeated exposure	US (MMC)
Population level impact assessment	US (MMC)
Risk assessment and management framework	US (NOAA)
Long-term monitoring	UK (JNCC)
Noise source characterization	UK (JNCC)
Harmonization on national, regional & international level	Germany (BSH)

Research/Funding Priorities & Cost-Sharing Strategies: Presentations

1. BOEM's Investment to Understand Noise Impacts on Marine Mammals (Guan, US BOEM)
2. ONR Investment and Research Priorities (Weise & Weiss, US ONR)
3. Living Marine Resources RDT&E Program (Shoemaker, US Navy LMR)
4. JIP Sound and Marine Life Programme (Bucki & Hedgeland, JIP)
5. UK research programmes to understand marine mammal acoustic impacts (Canning, UK DEFRA)
   - Several UK government funding programs as well as industrial funders (e.g., ORJIP)
6. Wind at Sea Ecological Programme (Kinneging & Graafland, The Netherlands Rijkswaterstaat)

BOEM Bureau of Ocean Energy Management

Research/Funding Priorities & Cost-Sharing Strategies: Discussions

- International collaboration is essential, as the ocean is shared by many countries
- Need to overcome international limitations on funding and cost-sharing mechanisms.
  - In the US, funds from different sources often cannot mix, thus may need different statement of work (BOEM's example: either fund different part of the project or provide fund to one entity to manage subcontract(s))
- Compile information on funding cycle requirements for each funding agencies worldwide to facilitate collaboration
- Regular and frequent communication among funders to tackle issues like pooling money together
- The need to keep facilities that conduct captive animal hearing work
- The study of cumulative effects – long-term need and multiple partners

BOEM Bureau of Ocean Energy Management

Next Steps

- Workshop report
- Reach out to international funders to continue dialogue
- Exchange information on funding mechanism and funding cycles among international funders
- Calling additional international funders to participate (email shane.guan@boem.gov)
- Follow-up (expanded) workshop at AN2025 in Prague

BOEM
Bureau of Ocean Energy Management

BOEM.gov

Shane Guan, Ph.D., shane.guan@boem.gov

U.S. Department of the Interior (DOI)

DOI protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

BOEM’s mission is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.