LMR 2024

U.S. NAVY'S LIVING MARINE RESOURCES PROGRAM ANNUAL REPORT

JUNE 2025

LMR 2024

U.S. NAVY'S
LIVING MARINE RESOURCES PROGRAM
ANNUAL REPORT

Table of Contents

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INSIGHTS

Welcome to our annual update on the Living Marine Resources (LMR) Program. This report provides an overview of the valuable work performed by all LMR participants to support the Navy's ability to train, test and be mission ready. The Program Overview section (starting on page 10) summarizes how the LMR program supports Navy readiness and outlines how we coordinate with other Navy programs and federal agencies to increase program efficiency. These efforts have leveraged over $16 million of additional funding toward mutual benefit since 2014.

This year marks a decade that we have been managing the LMR program and we have seen many significant accomplishments that support the Navy. See the graphic of LMR major accomplishments included on pages 8 and 9.

The Program Portfolio section (starting on page 20) includes background and updates on our many technical projects. In 2024, the LMR program was managing 27 projects, all carefully selected to meet specific Navy-defined priority needs. These projects include five new projects, 11 ongoing projects and 11 projects that were completed during 2024.

Chief MC John R. Fischer

Products from the completed projects are being delivered to the Navy end users. While results from all the 11 completed projects are contributing to Navy compliance, we want to note a few projects. One completed project investigated the potential auditory impacts to bottlenose dolphins from a continuous active sonar (CAS) signal (Project 51, page 54). Data from this project improve criteria and threshold inputs to the Navy Acoustic Effect Model (NAEMO), increasing the accuracy of estimated impacts from activities using the CAS signal. Another completed project investigated a vital data gap on cue rates, which are needed to accurately estimate animal abundance for impact assessments based on passive acoustic monitoring on Navy ranges (Project 42, page 37). Lastly, one completed project was an interagency coordination to develop standardized analysis methods for large passive acoustic datasets needed to efficiently navigate and process the data (Project 66, page 60).

A list of 190 publications issued from 2013 through 2024 is available under the Publications tab on our website, exwc.navfac.navy.mil/lmr.

Results from all these current and past projects continue to contribute to the scientific literature that provides critical, well-founded scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) planners, regulators, scien-

MC3 Elexia Morelos


MC2 Dylan M. Kinee

tists and other stakeholders. Twenty-five citations for 2024 publications are listed in the Publications section of this report (page 118). A list of 190 publications issued from 2013 through 2024 is available on our website (exwc.navfac.navy.mil/lmr) under the Publications tab.

The LMR program continues to be valuable to the current and future Navy mission because of your involvement.

We want to highlight the critical role played by our resource sponsor, the Chief of Naval Operations for Fleet Readiness and Logistics (OPNAV N4), and all the members of our management team, including the Fleet and SYSCOM representatives on the LMR Committee. Your participation and support keep the program focused on priority needs and well-coordinated with other Navy efforts. The LMR program continues to be valuable to the current and future Navy mission because of your involvement.

Anu Kumar, Program Manager

Mandy Shoemaker, Deputy Program Manager

LIVING MARINE RESOURCES
MAJOR TECHNICAL ACCOMPLISHMENTS

2013
- Conducted first marine mammal exposure experiment with a U.S. Navy DDG using operational mid-frequency sonar (53C)
- Transitioned marine mammal hearing topic from ONR to LMR

2014
- Published deepest dive ever recorded (goose-beaked whale)
- Published first risk function based on operational Navy sources at AUTEC (Blainville's beaked whale)

2015
- Initiated first external collaboration (non-Navy) and leveraged funding project, updating Marine Mammals and Noise book
- Started investigating effect of relevant U.S. Navy operational signal duty cycles on marine mammal hearing
- Co-funded the Behavioral Response Research and Evaluation Workshop (BRREW) to reprioritize BRS investments

2016
- Awarded first LMR bird and fish studies
- Transitioned the digital acoustic recording tag (DTAG) to enable commercial availability
- Conducted first marine mammal exposure experiment with a U.S. Navy helicopter using operational dipping sonar (AN/AQS-22)

2017
- Transitioned exposure experiments using operational mid-frequency sonar (53C) to the U.S. Navy Marine Species Monitoring program
- Invested in the Density Modelling (DenMod) workgroup to advance methods and encourage collaboration among interagency stakeholders

2018
- Published first American National Standards Institute (ANSI) standard focused on auditory evoked potentials data collection in cetaceans
- Conducted explosive exposure experiment on fish, in coordination with U.S. Navy explosive ordnance disposal team EODMU3 DET SW

LIVING MARINE RESOURCES
MAJOR TECHNICAL ACCOMPLISHMENTS

2019

- Collaborated in first inter-agency investment in large whale hearing, via the Subcommittee on Ocean Science and Technology (SOST)
- Started investigating effect of animal cue rates on passive acoustic based density estimates
- Started investigating population consequences of disturbance (PCOD) analysis methods
- Awarded first LMR turtle hearing study

2020

- Leveraged Small Business Innovative Research (SBIR) program to advance passive acoustic monitoring of marine mammals using underwater gliders
- Maintained progress toward research goals during COVID-19 pandemic by focusing on data analysis and publications when field work was delayed

2021

- Conducted far field measurements of under-water propagation from a U.S. Navy full ship shock trial, USS *Gerald R. Ford* (CVN 78)
- Improved animal tag attachment duration by modifying the material and micro-texture of the suction cups

2022

- Started investigating effect of U.S. Navy operational sonar signal durations on perceived loudness of marine mammals
- Started investigating effect of U.S. Navy Surveillance Towed Array Sensor System (SURTASS) Low Frequency Active (LFA) sonar on marine mammals
- Developed an unclassified sonar detector and standard-ized sonar nomenclature report for use by researchers analyzing passive acoustic data

2023

- Conducted field measurements of underwater propagation from surface detonations, in coordination with U.S. Navy explosive ordnance disposal team EODMU3 DET SW
- Conducted first direct measurement of hearing in a large whale (minke whale)
- Co-funded the Sound Cooperative at the National Centers for Environmental Information (NCEI) to support a national cyberinfrastructure capability for passive acoustic monitoring (PAM) data

2024

- Started investigating effect of U.S. Navy activities involving explosives on the behavior of marine mammals
- Surpassed 180 peer-reviewed scientific publications available for use in the Navy's at-sea compliance process
- Published first direct measurement of hearing in a large whale (minke whale) in the prestigious peer-reviewed journal *Science*

OVERVIEW

Mission

The Living Marine Resources (LMR) program's fundamental mission is to defend the Navy's ability to conduct uninterrupted at-sea training and testing, which preserves core Navy readiness capabilities.

The LMR program is an applied research program, sponsored by Chief of Naval Operations for Fleet Readiness and Logistics (N4), that funds Navy-driven research needs to support at-sea compliance and permitting.

NAVY READINESS DEPENDS ON COMPLIANCE WITH FEDERAL LAWS

For the Navy to be ready to fulfill its mission—to "maintain, train, and equip combat-ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas"—personnel must be able to train and test using realistic methods. To ensure uninterrupted training and testing, the Navy is responsible for compliance with a suite of federal laws and regulations such as the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA).

> Compliance with federal laws and regulations is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

As part of the regulatory compliance process associated with these Acts, the Navy is responsible for assessing the potential impacts from military readiness activities. The Navy is required to apply for permits to conduct activities that may result in impacts to protected species regulated under federal statues such as ESA or MMPA.

Once permits are obtained, there are requirements set forth that the Navy must follow to maintain compliance. These requirements include

- Implementing mitigation measures to reduce potential impacts
- Implementing a monitoring program to collect data that will enable a better understanding of the animals and how Navy activities might affect them
- Reporting annually on applicable training and testing activity execution.

Without permits, the Navy risks not being able to train or test. Without training and testing, the Navy cannot be ready to meet its mission. Compliance with federal laws and regulations is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

NAVY PROGRAMS THAT ENABLE COMPLIANCE WITH FEDERAL LAWS

In conjunction with other investments, the U.S. Navy funds three main programs to support at-sea compliance and permitting. These programs progress from basic research to applied research to monitoring implementation. The three programs are

- The Office of Naval Research Marine Mammals and Biology program (ONR MMB)
- The LMR program
- The U.S. Navy Marine Species Monitoring (MSM) program.

To promote ongoing coordination among all investments supporting compliance and permitting, the program manager from ONR MMB, representatives from the MSM program and representatives that manage other related investments are members of the LMR Committee (LMRC) (described on page 14).

The Office of Naval Research Marine Mammals and Biology Program

The ONR MMB program is the Navy's basic (6.1) and early applied (6.2) research program on marine mammals and biology. This program supports science-driven research related to understanding the effects of sound on marine mammals, including physiological, behavioral and ecological effects, as well as population-level effects. As a basic and early applied research program, this program focuses on new cutting-edge research topics and exploratory and developmental technological solutions, which help to advance the state of the science. These projects can often have high technical risk and long timelines.

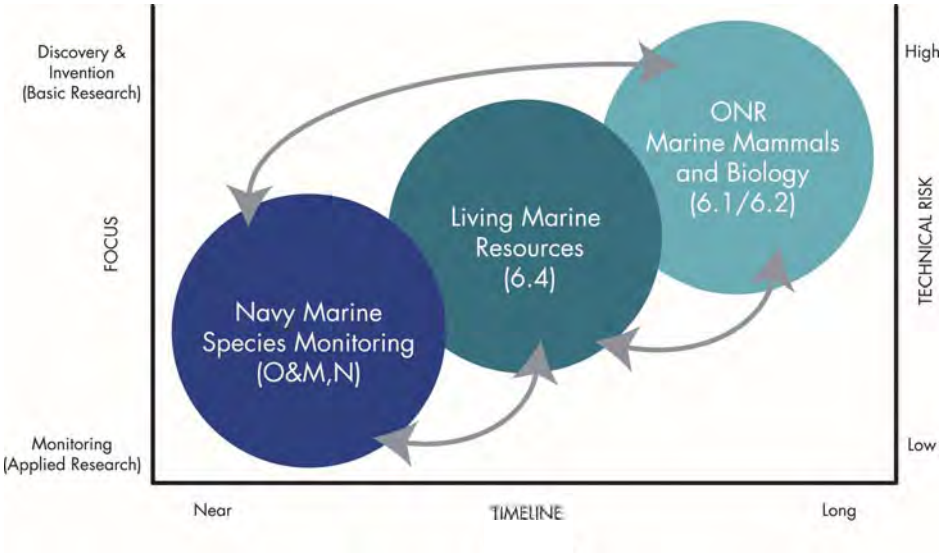
Outcomes from this program are often transferred to the LMR program to continue to develop, demonstrate and validate solutions, and then link products directly to an end user need. In some cases, outcomes can be delivered directly to the Navy MSM program or compliance process if ready for integration.

The Living Marine Resources Program

The LMR program is structured to focus on outcomes for Navy end users and to address the needs of Navy at-sea compliance and permitting. As a 6.4 late-stage applied research program, LMR develops, demonstrates, validates and assesses the data, methods and technology solutions needed to analyze the potential impacts from Navy training and testing activities on protected living marine resources.

MC2 Olivia Rucker

The LMR program serves multiple unique functions that the other two programs cannot provide. These functions help to address priority, end user-focused needs at the applied research level:



- Anticipate and conduct research on potential impacts resulting from new Navy sources (e.g., continuous active sonar)
- Collect and evaluate data pertaining to criteria and thresholds in support of the Navy Acoustic Effects Model (NAEMO)
- Conduct research on ESA-listed species other than marine mammals (e.g., fish, sea turtles, birds)
- Demonstrate and validate technologies, tools, models and methods.
- Develop standards and metrics for data collection or analysis

LMR provides a clear path for getting solutions and results to those who need them.

The LMR efforts are critical to ensuring an efficient process for obtaining the most effective tools and reliable data to support at-sea compliance and permitting. By providing a centralized program to address the Navy end users' stated needs, LMR provides a clear path for getting solutions and results to those who need them.

U.S. Navy Marine Species Monitoring Program

The U.S. Navy's MSM program is a requirement of the Navy's permits for training and testing. The primary objectives are to

- Monitor and assess the effects of Navy activities on protected marine species
- Ensure that data collected at multiple locations are collected in a manner that allows comparison between and among different geographic locations
- Add to the overall knowledge base of protected marine species and the effects of Navy activities on these species.

Since this program is requirements-driven, the projects should have low technical risk and often have short timelines. This demands proven tools and methods that have already been developed under the ONR MMB program, and field tested/validated or developed by the LMR program.

As the above chart shows, there is significant interplay of projects and support among the three programs, yet each serves a distinct role in the compliance process. When an ONR MMB project is deemed ready to move to the next stage of

MC2 Nettie Mae Manfull

development, it might be selected for continued development, demonstration and validation within LMR. Following LMR-funded demonstrations and refinements, products can become reliable components of the monitoring program or results can be directly incorporated into compliance documentation. In some cases, when a technology or method is ready for application, it will be transferred directly from ONR MMB development to the monitoring program.

The main goal of all three programs is to support the Navy in collecting all data and information necessary to obtain or comply with permits and ensure uninterrupted training and testing.

It is important to note that the main goal of all three programs is to support the Navy in collecting all data and information necessary to obtain or comply with permits and ensure uninterrupted training and testing.

STRUCTURE

The LMR program structure was carefully defined to ensure robust communication among Navy commands, other program managers and the LMR resource sponsor—OPNAV N4. The organization bolsters program communication, accountability and credibility.

Committees

The LMR program is supported by two defined committees—the LMR Committee and the Technical Review Committee—as described below.

LMR Committee

The LMR Committee (LMRC) includes representatives from relevant Navy Fleet and Systems Command activities affected by at-sea compliance issues, as well as members of the Navy's research and monitoring community. The LMRC includes representatives from

- OPNAV N4
- Office of the Deputy Assistant Secretary of the Navy for Environmental and Mission Readiness (DASN E&MR)
- Commander, U.S. Pacific Fleet (PACFLT)
- U.S. Fleet Forces (USFF)

- Naval Information Warfare Systems Command (NAVWAR)
- Naval Sea Systems Command (NAVSEA)
- Naval Air Systems Command (NAVAIR)
- Naval Facilities Engineering Command (NAVFAC)
- ONR.

LMRC members provide critical Navy end user perspectives on many program components.

LMRC members provide critical Navy end user perspectives on many program components including defining needs, evaluating and ranking project proposals, participating in the annual In-progress Review and identifying pathways to transfer solutions to end users.

Technical Review Committee

The purpose of the technical review committee (TRC) is to serve as an expert panel to review proposals and provide feedback to the Navy regarding technical sufficiency. Based on the need topics for which the Navy solicits proposals, the TRC membership may change to ensure the committee possesses the relevant technical expertise required. The TRC consists of subject matter experts from within the Navy and from other federal agencies, industry or academia, as appropriate.

Program Office

The LMR program is managed by NAVFAC EXWC in Port Hueneme, California. The LMR program manager and the deputy program manager have the primary responsibility for executing the program.

Resource Sponsor

The LMR program is sponsored by OPNAV N4 through its RDT&E action officer. Among its many roles as program sponsor, OPNAV N4 provides the LMR program's annual funding, sets policy and guidance for the Navy's research priorities, approves the list of needs and authorizes new projects.

PROGRAM INVESTMENTS AND PROCESS

The LMR program follows a formal process each year—from identifying Navy needs that fall within program investment areas to providing solutions relevant to Navy at-sea compliance and permitting. The projects funded by the program are carefully selected to achieve the program's mission. Four key factors that guide project selection are

1. Program investment areas
2. Navy needs
3. Priority species and geographic regions
4. Coordination with other programs, agencies and research institutions.

Program Investment Areas

The program investment areas establish the broader boundaries within which the program works to achieve its mission. The investment areas also help to guide the annual process to identify Navy needs. The LMR investment areas are:

1. **Data to support risk threshold criteria**

   Goal—to improve the Navy's acoustic and explosive impact assessments and validate mitigation requirements. This information is critical to the Navy's at-sea compliance and permitting, and ultimately helps ensure uninterrupted training and testing.

Approach—obtain and analyze data on how well animals can hear, how and when animals may be exposed to acoustic and explosive sources, and how animals respond or are affected when exposed. The data are used to develop risk threshold criteria to inform the Navy's acoustic and explosive impact assessments. Projects in this area can include hearing studies, sound exposure and behavioral response studies.

2. **Data processing and analysis tools**

   Goal—to make required monitoring program data processing and analysis more efficient and cost-effective. These tools provide more productive, technologically advanced and practical solutions that improve the Navy's capability to utilize data and information, which supports the Navy's competitive advantage in the undersea domain. The ability to collect, process, exploit and disseminate vast amounts of information is key to continually advancing the Navy's undersea capabilities.

   Approach—develop tools to automate the processing of large amounts of data to reduce costs, increase productivity and provide consistency. Develop tools to improve existing data analysis methods or foster development of new methods, both of which provide improved data products and results. Projects in this area can include new detection and classification algorithms, improvements to software programs or development of novel analytical methods.

3. **Monitoring technology demonstrations**

   Goal—to further develop technology to improve field data collection methods. Specific emphasis is given to utilizing existing Navy technologies and sensors for advancing research and data collection. These technology investments enable efficient and cost-effective implementation of the Navy's MSM program to support at-sea compliance and permitting.

   Approach—demonstrate and validate system upgrades or advanced capabilities of new or existing monitoring technologies and platforms, including sensors, tags, moored devices, buoys and mobile autonomous devices. This investment area aligns with the goals of the Navy's Task Force Ocean to make every Navy platform a sensor for data collection.

4. **Standards and metrics**

   Goal—to establish interagency and scientific community standards and metrics for data collection, management and analysis. This facilitates information exchange, which is necessary to harness the capabilities of aggregated data to ensure the Navy maintains information dominance.

   Approach—promote data comparability and enable data aggregation from different datasets. Ensure consistent, agreed-upon standards and metrics to provide cost-effective improvements to data and results that can be utilized to establish policy and technical guidance. Projects in this area can include standards for data collection methods, standardized data management tools and new metrics for reporting performance of data analysis methods.

5. **Emergent topics**

   This investment area is reserved for other priority topics that are associated with emerging technologies or capabilities. This includes research needs that arise out of the Navy's compliance process, or topics that do not squarely fall within the preceding categories. In 2024, LMR did not have any investments within emergent topics.

New project selections are prioritized by current Navy need and some investment areas may not have projects every year.

Navy Needs

Within the defined investment areas, the LMR program refines its investment decisions based on Navy needs that meet one or more of the following conditions:

- Address challenges faced by the Navy at-sea compliance community to provide solutions that will reduce operational constraints.
- Address an existing gap in knowledge, technology and/or capability to provide flexibility to the Navy to achieve the mission.
- Fulfill a regulatory constraint or driver to ensure that Navy training and testing occurs in a legally compliant manner.

Anyone within the Navy may submit needs for consideration by the LMR program. For details on submitting needs, see the program website: exwc.navfac.navy.mil/lmr. Non-Navy personnel can discuss need ideas with a Navy employee for consideration. The Navy employee can choose to sponsor and submit externally generated needs as appropriate. Submitted needs are validated and ranked by the LMRC, and then recommendations are made to the OPNAV N4 resource sponsor.

LMR-sponsored projects are assigned within a need category. The need associated with a given project is identified in each project summary presented in the Portfolio section of the report.

Project Lifecycle

The program's annual project cycle begins with soliciting and defining Navy needs. (See previous section, "Navy Needs.") The needs are then the basis for issuing a proposal solicitation. The solicitation includes a Broad Agency Announcement for offerors that are outside the federal government. After the solicitation closing date, the proposal evaluation process—conducted by the LMRC, TRC and program managers—begins with a review to identify those proposals of greatest interest. After the proposal evaluations are complete, the program manager makes a final recommendation to the program sponsor of projects to be funded.

Funded projects are initiated with a project kick-off communication between the principal investigator and program managers to discuss project and program expectations. Discussions cover details such as project milestones, spending plan and financial expectations, reporting requirements and ongoing communication with the program. The goal is to establish a framework that promotes project success and keeps projects targeted on meeting Navy needs.

MC3 Kevin Tang

When a project approaches its completion and its results demonstrate that the product can successfully meet the Navy need, the program works to move the product into the hands of the appropriate Navy end users. Products can take a variety of forms depending on the project, such as data analysis results, analytical tools, standards or technology. While this stage represents the final step in the formal project process, the LMR program does continue to track a project's success and solicit feedback about the product integration.

MANAGEMENT AND COMMUNICATION TOOLS

To promote efficient management and progress toward meeting its goals and mission, the program works to ensure clear communication among all participants and interested parties. The primary tools for these efforts are summarized below.

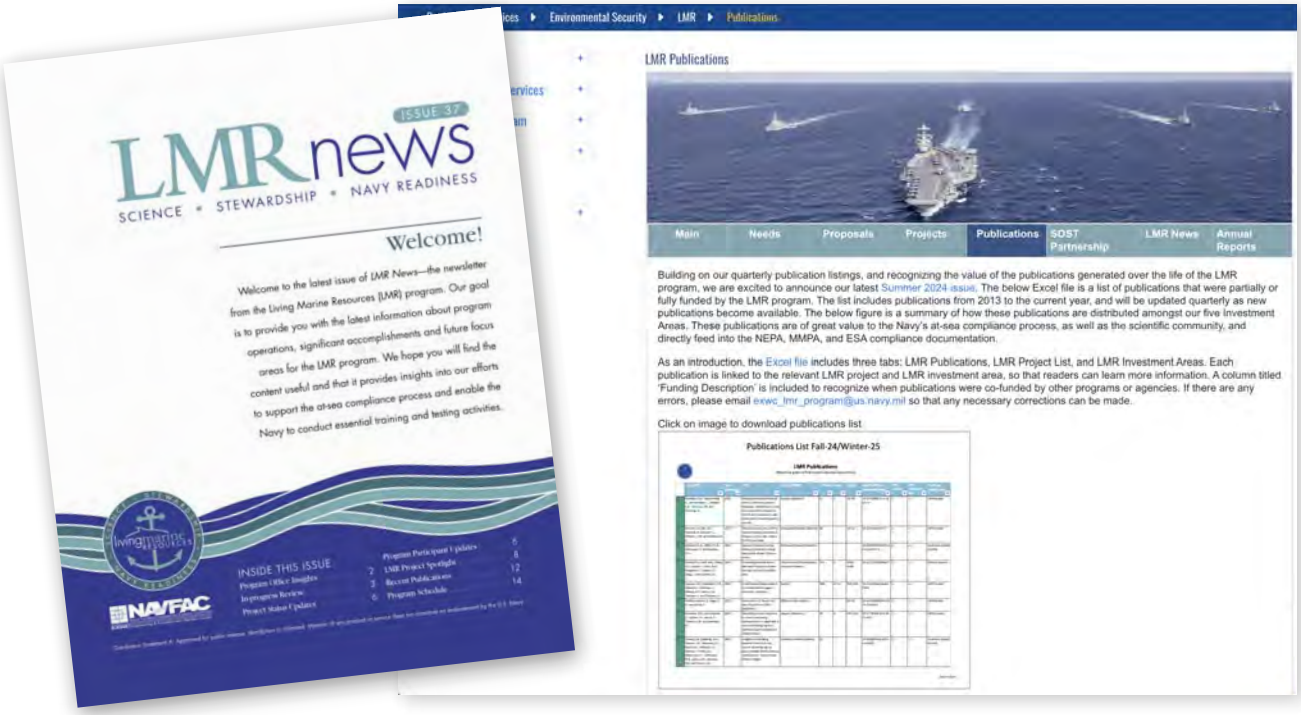
Newsletters

The LMR program issues a newsletter, *LMR News*, to provide readers with the latest information about program operations, significant accomplishments, milestones and future investment areas for the LMR program. The digital newsletter can be viewed at the LMR website.

Research Publications Spreadsheet

During 2020, the LMR program added a full listing of program research publications, in spreadsheet format, to the LMR website. At the close of 2024, the spreadsheet list included 190 publications, beginning in 2013 from the earlier Marine Mammal Research program, which preceded the LMR program's establishment. While the list focuses on publications resulting from Navy LMR funding, it also includes publications not specifically funded by the LMR program but that acknowledged use of data, methodology or technology developed with funding from LMR.

The spreadsheet provides full citations (authors, year, title, journal, issue, etc.) and, as appropriate, the LMR project number and investment area under which it was funded. In addition to journal publications, the spreadsheet includes entries for final and technical reports.



The spreadsheet is updated with the newsletter. To obtain the latest spreadsheet, go to exwc.navfac.navy.mil/lmr and click on the Publications tab.

Project Highlights Fact Sheets

Fact sheets highlighting key aspects of LMR-funded projects provide a quick view into program investments. The fact sheets, available on the LMR website, provide a summary of the following topics for each project:

- The need it addresses
- The solution
- The methodology
- The schedule
- Navy benefits
- End products
- Information about the principal investigator(s).

In-progress Review

Each principal investigator is required to provide a technical briefing to the LMRC and invited TRC subject matter experts at the program's annual In-progress Review (IPR). IPRs are typically held in the fall, after most field season efforts have concluded. The objectives of these IPRs are to review project progress, technical issues and accomplishments, integration issues and accomplishments, and to determine if any corrective actions are needed.

LMR Website

The program website—exwc.navfac.navy.mil/lmr—serves as a centralized repository for public information about the program. The site offers ready access to the newsletter, research publications list, project highlight fact sheets and annual reports. It also includes an announcement when a proposal solicitation is issued and provides information needed for proposal submission.

PORTFOLIO

Completed Projects

Eleven projects were completed during 2024 and are summarized in this section. Results from these projects are now available for use by the Marine Species Monitoring program and those involved in at-sea compliance.

- Project 37—Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales
- Project 38—Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds
- Project 40—Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles
- Project 41—Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags
- Project 42—ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation
- Project 45—Frequency-dependent Underwater TTS in California Sea Lions
- Project 46—Tethys Capability Enhancements
- Project 47—Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds
- Project 51—Dependence of TTS on Exposure Duration During Simulated Continuous Active Sonar: Examining the Equal-energy Hypothesis for Long-duration Exposures
- Project 65—Using Passive Acoustic Tracks from a Navy Array to Study Large Whale Behavior in the North Atlantic
- Project 66—Passive Acoustic Monitoring Access Network: Advancing Data Management and Cyberinfrastructure Solutions for a Big Data Problem

MC2 Carson Croom

LMR Projects

Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales

Principal Investigator: Dorian Houser
Project Status: Completed, Project 37

NEED

SOST Need: Development of Audiograms for Mysticetes

There is a need to improve understanding and measurement of auditory capabilities and sensitivities of low-frequency cetaceans (mysticetes) to anthropogenic sound. Research necessary to generate a mysticete audiogram includes developing and validating finite element modeling (FEM) methods, developing and testing *in situ* auditory evoked potential (AEP) measurement methods for mid- and high-frequency hearing sensitivities of mysticetes, developing tools for AEP measurements below 1 kHz, evaluating behavioral response methods and identifying other appropriate approaches or methods.

PROJECT

This project, funded in cooperation with the Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life (SOST ITF-ONML) (see the Partnerships section, page 115, for more information), obtained *in situ* auditory evoked potential (AEP) measurements of hearing sensitivity in a mysticete (baleen) whale, the minke whale (*Balaenoptera acutorostrata*). AEP methods involve measuring small voltages that the brain and auditory system generate in response to hearing a sound. Using AEPs to determine hearing sensitivity has been common practice in human and terrestrial animal research for decades. Over the last two decades, the technology also has been used routinely to test hearing in odontocetes (toothed whales), both small (e.g., dolphins and porpoises) and large (e.g., beluga, pilot and killer whales). The AEP hearing thresholds measured for minke whales are the first direct measurement of hearing in a mysticete.

The plan to measure the hearing of minke whales included temporarily confining animals in a fjord off the Norwegian coast. The team used AEP methods specifically modified for these animals. The research focused on small (3–5 meters long) juvenile minke whales because they were most suitable for handling and were expected to have good hearing capabilities, which increased the chance of success with the AEP methods. Juvenile minke whales are similar in size to wild beluga whales that have been temporarily caught and released for AEP testing.

Modifications to AEP methods largely consisted of adapting approaches previously worked out on smaller cetaceans with a special focus on customizing AEP recording parameters for this species. Researchers used acoustic stimuli with different acoustic bandwidths first to optimize data

First minke whale test of 2024.
Erica Staaterman

Surfacing minke whale.
Rolf Arne Ølberg

collection procedures and then to collect frequency-specific hearing thresholds, which could be used to begin the creation of a minke whale audiogram. Each whale tested was fitted with a satellite tag to monitor its behavior after release.

Following a one-year delay due to COVID-19 pandemic restrictions, the project conducted a feasibility field effort in 2021. This work, which included securing and deploying necessary equipment, provided valuable information for refining the field plan. Establishing the capture site, which required positioning and repositioning large, weighted nets proved to be more time-consuming than estimated. The combined length and weight of all the nets exceeds two kilometers and 20 tons, respectively. The team worked throughout the remainder of 2021 identifying solutions to logistical issues and shared recommendations with funding agencies, including a coordinated public outreach strategy, ahead of the next field effort. By the end of the season, the team had demonstrated that minke whales could be guided into and temporarily held in a net-enclosed basin. Based on the 2021 results and recommendations, the funding agencies approved a second field effort in 2022.

The project team reassembled in Norway in 2022 and implemented a revised setup plan that reflected lessons learned in 2021. After the catch system was in place and over the course of the following month, 41 minke whales were sighted near the catch system. Two animals were contained in the net-enclosed basin and corralled toward a smaller, net-enclosed fish farm modified for final containment and AEP testing. The first whale escaped through a gap between the catch system guide nets and the fish farm nets. After addressing the gap between the nets, the second whale was successfully corralled and placed in a net hammock for testing. Unfortunately, the whale exhibited signs of distress and the research team let the whale go after 26 minutes of being held. The experience provided the team with valuable lessons about how to modify the catch procedure to minimize stress on the whale. Importantly, they demonstrated that both the corralling approach and the procedure for holding the whale for a hearing test worked. The team

held regular meetings during the remainder of 2022 to identify and design necessary plan modifications to improve field effort success.

The project team returned to the field in 2023 with modified handling protocols and a change in the catch system design. Corralling procedures and the procedure for maneuvering whales within the fish farm into a hammock for testing were slowed and incorporated pauses that allowed the whale to adjust to changing conditions. These modifications substantially improved the results of the 2023 field effort. A total of 88 whales were observed near the catch system. Eight whales entered the catch basin, and two whales were successfully corralled and placed into the hammock for testing. Procedures for performing the AEP hearing test were established with the first whale and the team successfully recorded the whale's auditory brainstem response (ABR), which was the first step toward obtaining the audiogram. With the second whale, the team assessed the frequency range of hearing. Although the types of sounds used for testing were too broadband to precisely determine the upper-frequency limit of hearing in the whale, the results indicated that the whale's upper-frequency limit was between 45 and 90 kHz, which is higher than had been predicted for this species through anatomical modeling, vocalizations and behavioral responses to sound. Both whales were satellite tagged during the hearing test and showed species-typical dive and migratory behavior upon release, suggesting no long-term negative effects of the hearing test.

The team returned for a final season in 2024. With lessons learned from the prior three years, the guide-net system was once again modified to improve the whale catch efficiency. The modifications paid off as five whales were caught within the catch basin, while only 21 whales were observed over the season (four times fewer than observed in the prior year). Of the five whales caught in the basin, two were corralled into the

Satellite tag attachment on minke whale.
Rune Rolland

net hammock for testing. These whales provided the first thresholds of hearing for any mysticete whale. Thresholds were obtained at frequencies ranging from 5 to 64 kHz. No hearing threshold was obtained at 64 kHz in the largest animal tested but was obtained in the smallest animal tested. These data are consistent with the prior year's findings on the range of hearing in the minke whale and suggest that the upper limit of hearing probably occurs around 64 kHz. Surprisingly, the whales were most sensitive to 32 kHz and had a nearly flat region of sensitivity down to 4 kHz. As in the prior year, satellite tag data demonstrated that the whales continued their migration to foraging grounds north of Norway following the hearing tests. One tag persisted long enough to allow observation of the minke whale's southern migration as far south as the Azores.

> This study's results are invaluable to regulators, scientists, the U.S. Navy and others concerned with the potential impact of sound on mysticetes.

This study's results are invaluable to regulators, scientists, the U.S. Navy and others concerned with the potential impact of sound on mysticetes. The frequency-specific information obtained, particularly the upper-frequency limit of hearing and the region of best sensitivity, provide data needed for validating models of hearing in mysticete whales.

Techniques developed during the minke whale hearing tests will facilitate future audiometric measurements on other mysticete species. In 2024, the procedures for catching the whales were published in Aquatic Mammals, and the initial hearing test results describing the frequency range of hearing were published in *Science* (see Publications sidebar).

About the Principal Investigator

Dorian Houser is the Director of Conservation Biology at the National Marine Mammal Foundation (NMMF). Dr. Houser has spent over two decades in the study of how anthropogenic sound affects marine mammals and has been involved in the development of numerous impact statements for the U.S. government. He earned his Ph.D. in biology from the University of California Santa Cruz.

Co-PIs are Jason Mulsow, Ph.D. (NMMF), Petter Kvadsheim, Ph.D. (Norwegian Defence Research Establishment), Lars Kleivane, MSc (LKARTS Norway), James Finneran, Ph.D. (U.S. Navy Marine Mammal Program) and Rolf Arne Ølberg, DVSc (Kristiansand Dyrepark).

Publications

Kleivane, L., Kvadsheim, P.H., Vinje, A.V.P., Mulsow, J., Ølberg, R.A., Teilmann, J., Harms, C. and Houser, D. (2024). Capture and release of minke whales offers new research opportunities, including measurements of mysticete hearing. *Aquatic Mammals*, 50(4):352-368. DOI 10.1578/AM.50.4.2024.352.

Houser, D.S., Kvadsheim, P.H., Kleivane, L., Mulsow, J., Ølberg, R.A., Harms, C.A., Teilmann, J. and Finneran, J.J. (2024). Direct hearing measurements in a baleen whale suggest ultrasonic sensitivity. *Science*, 386(6724):902-906. DOI 10.1126/science.ado7580.

Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds

Principal Investigators:
Rebecca Dunlop, Michael Noad
Project Status: Completed, Project 38

NEED

SOST Need: Development of Audiograms for Mysticetes

There is a need to improve understanding and measurement of auditory capabilities and sensitivities of low-frequency cetaceans (mysticetes) to anthropogenic sound. Research necessary to generate a mysticete audiogram includes developing and validating finite element modeling (FEM) methods, developing and testing *in situ* auditory evoked potential (AEP) measurement methods for mid- and high-frequency hearing sensitivities of mysticetes, developing tools for AEP measurements below 1 kHz, evaluating behavioral response methods and identifying other appropriate approaches or methods.

PROJECT

This project, funded in cooperation with the SOST ITF-ONML (see the Partnerships section, page 115, for more information), addressed that portion of the need related to using behavioral response methods to test the hearing sensitivities of large whales. The project team organized and conducted a project plan for measuring the behavioral response of migrating humpback whales *(Megaptera novaeangliae)* to tones of various frequencies to infer their hearing sensitivity at each frequency. These behavioral response experiments serve as a proxy for audiometric measurements to estimate hearing sensitivity in baleen whales.

The project team conducted a series of field experiments in a unique site near Queensland, Australia. The team's field plan included both a team of land-based visual observers, who recorded the movement and dive behaviors of focal groups of whales during the experiments, and on-water teams. Working from a small research vessel, the on-water team members attached motion and sound recording tags to some of the whales to record fine-scale changes in movement and dive behavior as well as their acoustic surroundings.

Another on-water team deployed a sound source from a vessel, playing upsweep tones at various frequencies to approaching whales. The trials for

Approaching a whale to attach a motion and sound recording tag.
The Cetacean Ecology Group, University of Queensland, permit Queensland DES # WA0009021

Humpback whale.
NOAA/NMFS

each experiment followed a 'before/during' protocol, where the target whale group behavior was continually recorded 'before' and 'during' the tone playback. The playback began when the whales were too far from the source to hear it (based on assumptions about their hearing in noise). The source level of the tone remained constant throughout each trial. As the whales approached the sound source, the received level of the tones at the focal group increased until the tones became audible to the whales. At this point, the focal group usually changed behavior by temporarily stopping, changing direction to avoid the vessel and/or changing dive behavior. The received level was measured at the point at which they changed behavior, giving an indication of detection-and-response threshold of the signal in noise. This was repeated multiple times for each frequency, using different groups of whales. Trials in which the vessel was present, but no tones were transmitted, were also conducted to provide a control sample. This was to ensure that the response was to the tone stimulus and not the presence of the vessel.

A four-phase experimental routine was followed:

1. Tagging phase—Attempt to tag an adult whale in the experimental group.
2. Before phase—Follow the group without interference to observe normal behavior and move the source vessel into position ahead of the projected path of the group.
3. During phase—Operate the sound source as the group approaches until the group responds by avoiding the acoustic source/vessel.
4. After phase—Conduct additional *in situ* acoustic measurements and recover tag if deployed.

The study site provided several benefits: lower noise levels than many ocean sites; an extensively measured and characterized acoustic context; and a wealth of background data on whale movements, normal behaviors and abundance based

Land-based observation team on Emu Mountain.
The Cetacean Ecology Group, University of Queensland

on 11 previous field seasons. These benefits supported tagging efforts and facilitated detecting responses to the sound source.

The original project schedule included a full field season in 2020. However, the field effort required skilled observers who would need to travel to, and be lodged in, the area. When the COVID-19 pandemic restrictions prevented travel into Australia and Queensland, as well as severely limiting lodging options, the core project team revised their 2020 plan. Rather than lose an entire year, the two principal investigators conducted a pilot effort without assistants. Working at the planned site, they tested equipment and evaluated signal transmission and measurement under real field conditions.

Although the 2021 field season was also affected by pandemic travel restrictions, reducing volunteer staffing for the land-based observers by approximately one-third, a field effort was conducted. Results of the test runs in 2020 significantly improved on-water efficiency in the 2021 field efforts. The team completed 15 experiments: one control (no signal), five 1 kHz, six 4 kHz and three 16 kHz. Although tag deployment was successful (three out of three attempts resulted in a tagged whale), the tags did not release, and the data were not recovered.

During 2022, the team completed data analyses from the 2021 field work and used insights from that season to refine the experimental plan for the 2022 field efforts. With COVID restrictions removed, the team was able to employ a full complement of 12 volunteers, which significantly improved data collection. A total of 27 sound, three control (no sound transmission) and six baseline trials (i.e., no source vessel in area) were successfully completed. Frequencies tested in 2022 included 250 Hz (sweeping up to 315 Hz), 1 kHz (sweeping up to 1.25 kHz), 4 kHz (to 5 kHz) and 16 kHz (to 20 kHz). During five of the trials, Acousounde (sound recording) tags were deployed, with four successfully recording data (one failed to record). Data analyses were largely completed by the close of 2022 and the results

were used to inform the 2023 field plan. Preliminary results showed that the study design was effective at eliciting a response indicating whales heard the sounds.

In 2023 and 2024, the team conducted additional field trials, with 2024 being the final one. In 2023, a total of 32 sound trials and eight control trials were completed, with seven Acousounde tags successfully deployed and retrieved. Frequencies tested were 80 Hz, 250 Hz, 1 kHz, 4 kHz, 16 kHz and 22 kHz sweeps. The 2024 field effort completed the 80 Hz and 22 kHz dataset. Data analysis was also completed in 2024.

> Results will help to validate and integrate the modeling approach with real data.

Overall, the team completed 106 trials, with tagged animals in 12 of those trials. This total included 12 control trials. Data analysis showed that whales were consistently responding to all tested frequencies (80 Hz to 22 kHz). For each frequency, the lowest received level, and lowest received signal-to-noise ratio measured at the behavioral change-point, were used to infer the hearing sensitivity of humpback whales in natural noise. The final project report was submitted at the end of 2024. A peer-reviewed publication will follow in 2025.

The resulting information on humpback whale hearing, including data on how well humpback whales can hear under ocean noise conditions, will help regulators, industry and the U.S. Navy to model the potential effects of noise-producing activities on humpback whales. Results also will inform hearing models already developed for mysticetes, help to validate and integrate the modeling approach with real data, and provide a robust measure of humpback whale responses to tones under realistic conditions. Hearing data can also be incorporated into models used to assess the effects of various sound sources on mysticete behavior and physiology.

About the Principal Investigators

Rebecca Dunlop is an associate professor in physiology and animal behavior at the School of Biological Sciences, University of Queensland, Australia. Dr. Dunlop earned her Ph.D. in neuroethology from The Queen's University of Belfast, Ireland. Her current research focuses on humpback whale behavior, social communication, physiology and the effects of anthropogenic noise.

Michael Noad is a professor at the School of Veterinary Science, University of Queensland, Australia. Dr. Noad earned his Ph.D. from the University of Sydney, Australia. His current work focuses on the evolution and function of humpback whale song, population ecology and effects of noise.

Publication

Dunlop, R.A., Noad, M.J. and Houser, D. (2023). Using Playback Experiments to Estimate the Hearing Range and Sensitivity in Humpback Whales. In: Popper, A.N., Sisneros, J., Hawkins, A., Thomsen, F. (eds) The Effects of Noise on Aquatic Life. Springer, Cham. DOI 10.1007/978-3-031-10417-6_44-1.

Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles

Principal Investigators:
Aran Mooney, Wendy Piniak
Project Status: Completed, Project 40

NEED

N-0208-19: Turtle TTS Feasibility Study

The Navy, National Marine Fisheries Service (NMFS) and other federal agencies require quantitative thresholds to examine the potential impacts of underwater sound on protected species. Basic audiometric information is available for some sea turtle species, however, data on the susceptibility of sea turtles to noise induced hearing loss (threshold shifts) is lacking. There is a need to obtain auditory temporary threshold shift (TTS) information for sea turtles. Due to their protected status under the Endangered Species Act, it is necessary to first determine the feasibility of generating TTS in a closely related surrogate—a non-ESA listed turtle species (e.g., red-eared slider, eastern painted turtle, pond slider, etc.). If feasible, steps to obtain TTS information for an ESA-listed sea turtle may be undertaken in follow-on research efforts.

PROJECT

This project examined auditory TTS in two species of freshwater aquatic turtles and provided the cumulative sound exposure levels and durations that induce TTS in these species. The work also included investigating if evidence of TTS can be detected using standard imaging techniques (e.g., computed tomography), potentially allowing an efficient method to assess auditory impacts on noise-exposed turtles. Results are providing researchers, managers and stakeholders critical data to improve estimates of acoustic effects to both freshwater and sea turtles. Results also are being evaluated relative to appropriate mitigation measures to reduce potential effects to sea turtles from low-frequency anthropogenic sound. This project was co-funded by the LMR program and National Oceanic and Atmospheric Administration (NOAA).

> Because no TTS data previously existed for turtles, the audiograms and TTS data produced by this research provide appropriate data when developing the next phase of TTS criteria.

Underwater hearing measurements and TTS assessments were conducted with two freshwater turtle species—the eastern painted turtle (*Chrysemys picta picta*) and red-eared slider (*Trachemys scripta elegans*). The team used auditory evoked potential (AEP) methodology to measure baseline hearing thresholds and hearing after controlled sound exposures. They tested two species to develop robust TTS measurements supported by multi-species comparisons and to identify if there are methodological challenges/differences between species. Additionally, comparing TTS onset and growth in the two surrogate taxa contributed to understanding potential TTS variability between turtle species. Examining potential TTS in multiple animals allows for additional measurements of variability. Initial AEP measurements of hearing sensitivity were followed by sound exposure trials and anatomical imaging as summarized below.

- **AEP testing**

  Baseline hearing sensitivity was measured by recording AEPs, a rapid, non-invasive technique that is used to measure hearing in a

varied array of taxa including fishes, squid, seabirds, odontocetes, manatees, pinnipeds, sharks and sea turtles.

Initial hearing thresholds to determine baseline audiograms were measured at a variety of frequencies between 50 and 1,800 Hz for each species. This general method is well-established although the team developed means to repeatedly measure turtle hearing (within and across days and months, seasons and years), to understand variability and track recovery to baseline after noise exposure. The testing range encompassed the full frequency range of turtle hearing. At each frequency, sound levels were decreased until AEP responses were no longer detected (threshold). These data added to understanding of hearing in red-eared sliders and defined the audiogram for Eastern painted turtles.

- **Sound exposure trials**

  Sound exposure trials tested the durations and sound pressure levels (SPLs) required to induce TTS onset and develop an empirically based predictive curve of TTS onset and growth. The initial trials exposed turtles to broadband white noise that spanned their auditory frequency range and was predicted to cause TTS. Fatiguing noise SPLs started at lower levels and increased or decreased as needed to induce TTS (up to certain SPLs) in a semi-random manner. Similarly, durations were increased or decreased to achieve targeted

Eastern painted turtle.
Andria Salas


Green sea turtle.

overall sound exposure levels (SELs) that produced a range of TTS magnitudes. Results from this broadband study led to additional TTS experiments testing auditory effects of narrowband sound and intermittent fatiguing noise. Results were collected into a TTS SEL (SPL vs duration) matrix for each species. The matrix provides a visual presentation of the test frequency and exposure time by sound pressure level for each animal tested. These data have been used to define TTS sensitivity across different frequencies for both species and allow us to evaluate how species may differ in TTS susceptibility.

- **Anatomy**

  The project also examined the similarities and potential differences of the auditory anatomy after a noise exposure compared to a control for each turtle. After exploring multiple methods, a non-terminal approach was identified that could be applied to both species for comparison. The team transported the turtles and sound exposure tank and equipment to a veterinary school, where they underwent computerized tomography (CT) and magnetic resonance imaging (MRI) scans after a control "exposure" and, on a following trip, after a high SEL sound exposure shown to produce significant TTS. The gross ear anatomy and lungs were evaluated for potential noise effects to identify potential short-term anatomical changes that might indicate TTS or other damage to sensitive air spaces. Defining methods by which to assess damage would support examining other turtle species in the future.

Based on the results of these efforts, the team created dose-dependent models of TTS for each

species. Models were also created and compared for different auditory frequencies. This information will allow regulators and data users to predict the sound levels and durations that may produce TTS onset in turtle species for different noise types. The observed TTS recovery patterns and safety measures demonstrated in these AEP and experimental methods are helping to define strategies to study TTS in sea turtles.

Because no TTS data previously existed for turtles, the audiograms and TTS data produced by this research are informing analyses of the effects of sound-producing activities on both freshwater and sea turtles and they provide appropriate data when developing the next phase of TTS criteria. The team worked with the Navy's at-sea compliance team as these data were incorporated into criteria analyses. The project has also provided protocols that will contribute to future investigations of noise-induced hearing loss in other turtle species, including sea turtles.

Key contributor: Andria Salas (Woods Hole Oceanographic Institution).

About the Principal Investigators

Aran Mooney is an associate scientist in the biology department at the Woods Hole Oceanographic Institution, where he leads the Sensory Ecology and Bioacoustics Laboratory. His research addresses how marine animals detect and use sound and how animals may be affected by anthropogenic noise. Dr. Mooney holds a Ph.D. in zoology (marine biology emphasis) from the University of Hawaii.

Wendy Dow Piniak is a biologist at NOAA's NMFS. Dr. Piniak's research focuses on sea turtle biology, conservation, and acoustic ecology. She has experience measuring turtle hearing and conducting field studies examining sea turtle behavioral responses to sound. Dr. Piniak holds a Ph.D. in marine science and conservation from Duke University.

Publications

Salas, A.K., Sims, M.A., Harms, C.A., Piniak, W.E.D. and Mooney, T.A. (2024). Narrowband noise induces frequency-specific underwater temporary threshold shifts in freshwater turtles. *JASA Express Letters*, 4(8). DOI 10.1121/10.0028321.

Salas, A.K., Capuano, A., Harms, C.A., Piniak, W.E.D. and Mooney, T.A. (2024). Frequency-dependent temporary threshold shifts in the Eastern painted turtle (*Chrysemys picta picta*). *The Journal of the Acoustical Society of America*, 155(5):3254-3266. DOI 10.1121/10.0026021.

Salas, A.K., Capuano, A.M., Harms, C.A., Piniak, W.E.D. and Mooney, T.A. (2023). Temporary noise-induced underwater hearing loss in an aquatic turtle (*Trachemys scripta elegans*). *The Journal of the Acoustical Society of America*, 154(2):1003-1017. DOI 10.1121/10.0020588.

Salas, A.K., Capuano, A.M., Harms, C.A., Piniak, W.E.D. and Mooney, T.A. (2023). Calculating Underwater Auditory Thresholds in the Freshwater Turtle *Trachemys scripta elegans*. In: Popper, A.N., Sisneros, J., Hawkins, A.D., Thomsen, F. (eds) The Effects of Noise on Aquatic Life. Springer, Cham. DOI 10.1007/978-3-031-10417-6_142-1.

Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags

Principal Investigator: Russ Andrews
Project Status: Completed, Project 41

NEED

N-0203-19: Improvement of Medium-term Telemetry Tag Attachment Duration

The Navy requires data to support behavioral response criteria in its acoustic effects modeling. Animal telemetry (i.e., tagging) provides much of the needed marine mammal baseline behavioral data (diving, movement) and behavioral and physiological response to exposure from Navy sources. Longer tag attachment durations could offer improved data to better understand the duration and severity of behavioral responses to anthropogenic noise. The Navy is interested in research towards the redesign and/or improvement of medium-term tag attachment methods for dart style tag attachments for marine mammals. Improved dart design is needed to increase tag deployment durations to an average of one to several months.

PROJECT

This demonstration project worked to assess the feasibility of producing an alternative tag attachment element for remote tag deployment. The current attachment for the Low Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) tag system employs darts—small diameter metal shafts with externally facing barbs, or petals. A significant concern is how these rigid anchors interact with the surrounding tissue when the external part of the tag is subjected to large dynamic forces (including physical contact with other animals and the seafloor or breaking the water surface), which are common occurrences for many tagged cetaceans.

Project goals were to explore attachment mechanisms that would be

- More compatible with the animal's tissue
- Less susceptible to breakage
- Well-balanced with the external tag electronics package
- Easily attached
- Able to remain attached for longer periods
- Designed to work with the current suite of LIMPET tags and Sound and Motion Recording and Transmitting (SMRT) tags.

The project was originally organized into four separate phases, with implementation of each

Aerial view of a deployment of the Design 1 elastic anchors system on a short-finned pilot whale in Hawaii, October 2023.
Cascadia Research Collective, permit 26596

Images immediately before and after the attachment of the Design 1 elastic anchors system on a short-finned pilot whale in Hawaii, October 2023.
Cascadia Research Collective, permit 26596

subsequent phase determined by the outcome of the preceding one.

- **Phase 1**

  Refine two existing designs: (1) an elastic connection between a more tissue-friendly implanted anchor and existing LIMPET external package and (2) a single-point attachment, loosely tethered tag.

- **Phase 2**

  Conduct field deployments of the most promising designs identified in Phase 1.

- **Phase 3**

  Implement the lessons learned from field trials to improve the attachment element design(s). Demonstrate the final design in field trials with the same two species chosen for Phase 2. Prepare a final report on the field trials.

- **Phase 4**

  Conduct dedicated detailed follow-up studies to assess the condition of the previously tagged whales and demonstrate that the improved anchor design has not increased the negative effects of tagging. This will include quantifying wound healing and the effects of tagging on whale survival, reproduction and behavior. The team will use high-resolution digital photos, histological examination of biopsy samples and imaging from forward-looking infrared (FLIR) cameras to examine how well tag attachment sites are healing and to evaluate thermoregulatory function in the dorsal fin. The diving and movement behavior of tagged animals will also be evaluated.

Phase 1 of the project, originally slated for completion in 2020, saw some COVID-19-related changes and delays. When personnel and access to real whale tissue became limited, the work plan had to be modified. Computer modeling of tissue and prototype anchor interactions stopped and work then focused more on physical prototype design and testing. This included developing appropriate simulated tissue for repeated testing of attachment designs. Once a material was developed, various prototypes of the two attachment designs were tested, including comparing insertion force and retention strength. Additionally, because the new attachments may be heavier than existing darts, the project team reviewed available projectors for remote tag delivery to determine whether new off-the-shelf options could be used successfully with heavier, more robust tag attachments.

The project was able to proceed with Phase 1 design and testing in 2021, completing two new designs, and lab and simulated field tests of both designs. The key elements for redesign were the terminal anchor and attachment materials. Design 1 used an elastic connection between a more tissue-friendly anchor and an off-the-shelf LIMPET satellite tag external package. Design 2 used a single-point attachment with a loosely tethered tag. Lab tests of

the designs evaluated multiple criteria, including measures of insertion impact and retention strength. Both prototype designs met all defined testing criteria, qualifying them for field demonstration.

This project is an excellent example of why it is so important to have the LMRC members and project PIs work closely together to continue to evaluate project progress.

The team conducted Phase 2 field tests of Design 1 with pilot whales in Hawaii in 2022. The tag holders appeared to be a weak spot, with undesired breakage. Only two deployments were attempted and neither of them implanted to the desired depth. Remaining work in 2022 focused on reconfiguring the tag holder and insertion rods, followed by simulation tests.

Following tests that demonstrated that the redesigned tag holder/insertion device was robust, a second Phase 2 field effort was conducted with short-finned pilot whales in Hawaii in October 2023. An unusually low encounter rate with pilot whales severely limited deployment opportunities, but four of the Design 1 elastic anchors system ultimately were deployed. One tag failed upon impact due to an unexpected vulnerability of the antenna, but this was addressed with a slight modification of the tag holder. The other three tags transmitted for between 13 and 21 days.

In 2024 additional research sought to address failure points, including making the elastic element of the elastic anchors smaller to reduce the required insertion force. Lab tests on prototypes revealed that the modified anchors were damaged on insertion. It was determined that the design was not ready to be deployed in the field for further testing in 2024.

After careful consideration, the LMRC and the PI decided that the research should return to the basic research level for further development. Therefore, Phases 3 and 4 was not funded. This project is an excellent example of why it is so important to have the LMRC members and project PIs work closely together to continue to evaluate project progress. The LMR program funds applied research and sometimes project investments demonstrate that more development work is needed. The final report identified the type of additional research that might address the issues. The need for longer duration tag attachments remains valid and the LMR program will continue to follow development progress for future consideration.

About the Principal Investigators

Russel Andrews is a senior scientist with the Foundation for Marine Ecology and Telemetry Research. His expertise includes marine mammals, diving behavior and physiology, and remote monitoring equipment and instrumentation. Dr. Andrews earned his Ph.D. in zoology at the University of British Columbia.

Greg Schorr, a research biologist at the Foundation for Marine Ecology and Telemetry Research, has been studying marine mammals for over two decades. His most recent focus has been using remotely deployed satellite tags to study beaked whale ecology and behavioral responses to anthropogenic sources of sound.

ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation

Principal Investigator: Tiago Marques
Project Status: Completed, Project 42

NEED

N-0205-19: Investigation of the Effects of Cue Rate and Cue Stability on Passive Acoustic Monitoring (PAM)-based Density Estimation Methods

Marine mammal density estimates are a critical input for the Navy's acoustic effects modeling. While visual aerial or shipboard surveys are standard methodologies for estimating marine mammal density, they can be very expensive to conduct, are limited both in their spatial and temporal coverage, and are not effective at documenting cryptic species (species that are difficult to see). Estimating density using fixed passive acoustic monitoring (PAM) has the potential to increase the amount of density data that can be used in the Navy's acoustic effects modeling. In some PAM-based density estimation (PAM-DE) methods, the "cue rate" or the marine mammal sound production rate is an important multiplier to get to a final density estimate. Cue rates can vary in marine mammals as a function of multiple factors, including time of day, year, group size, age, sex, behavioral state, season, bottom depth and location. Also cue rates often are determined from limited datasets and assumed to be representative for the species. The Navy needs recommendations of the most appropriate species for which to collect cue rate data and the appropriate cue rates to use in density estimates.

PROJECT

The ACCURATE project was designed to deliver a comprehensive, quantitative synthesis of the current state of knowledge on acoustic cue rates and cue rate stability for marine mammal density estimation from passive acoustics. Cue rate is a fundamental multiplier required to convert the number of detected sounds into an estimate of animal abundance or density. The ultimate project goal was to determine the most appropriate cue rates to use in different contextual settings. The project produced a considerable number of outputs, pushing the field forward to help to meet Navy needs. This information has been made publicly available to the wider scientific community involved in estimating density from passive acoustics.

The project tasks reflected existing knowledge and specific aspects of understanding cue rates. The tasks were

1. Bibliographic review and review paper
2. Process and analyze tags
3. Assess the factors informing cue rates
4. Cue rate variability over space and time
    a. Caller identification for baleen whales cue rates
    b. Cue rates from proxy data
    c. Deep diver cue rate variability
    d. Investigating deep diver inter-click interval (ICI)
    e. Detector/classifier implications for cue rates
5. Impacts of cue rate variability in density estimation (DE)
6. Dissemination and recommendations.

A more detailed overview of the tasks and objectives is available on the ACCURATE website (accurate.st-andrews.ac.uk/project-objectives).

The ACCURATE project began in 2020 with task 1 that included an extensive bibliographic search for peer-reviewed papers and grey literature reports and efforts to contact researchers involved in PAM work to understand existing, but unpublished, data sources. Project participants established multiple online options for other researchers to provide references and recommendations for PAM data

Sperm whale.

sources. (See the 2021 LMR Annual Report for a list.) The ACCURATE team collaborated with many other teams that had relevant data and information on the topic, with a natural focus on, but not exclusive to, other LMR-funded projects. A draft document summarizing the bibliographic review results, including the synthesis of identified datasets, was submitted to *Biological Reviews* in late 2024.

As part of task 2, team members also worked with researchers who deploy acoustic recording animal tags (e.g., DTAG, Acousonde) on marine mammals to secure digital acoustic tag data and extract whale vocalizations (e.g., click data). Tagged species for which some aspect of cue rate analysis was published include sperm whales (*Physeter macrocephalus*), pilot whales (*Globicephala melas*), blue whales (*Balaenoptera musculus*), goose-beaked whales (*Ziphius cavirostris*), Risso's dolphin (*Grampus griseus*), Blainville's beaked whales (*Mesoplodon cavirostris*), fin whales (*Balaenoptera physalus*), narwhals (*Monodon monoceros*) and southern right whales (*Eubalaena australis*). Cues and cue types from each processed tag were counted to obtain a cue rate per tag, which were then used to estimate cue rate per species. Where possible, factors affecting cue rate were identified.

A total of 862 tags were identified for potential further processing, although only a subset of these were effectively processed within ACCURATE. For sperm whales alone, approximately 170 DTAGs were processed producing almost eight million echolocation clicks that were analyzed. Data from the tags informed subsequent project tasks, including identifying factors that influence cue rate and caller identification for individual whales.

The significant data available from the bibliographic work and tag analyses supported other project tasks including assessing factors influencing cue rates, refining methods to identify cue rates from proxy data, evaluating deep diver cue rate variability and defining detector/classifier implications for cue rates.

Sperm whale and narwhal tag data were the focus for task 3, assessing factors informing cue rates. A paper comparing different methods for estimating cue rates from tag data using sperm whales was published (See Publications sidebar). Narwhal tag

data were similarly analyzed, with a manuscript about narwhals' cue rates using Acousonde data from Greenland published in 2024. Another narwhal-focused manuscript is expected to be submitted in 2025. The team anticipates additional publications based on the sperm whale DTAG dataset to be submitted in 2025, describing variability in cue rates across space and time and relating sound production to depth.

Tasks 4a and 4b expanded cue rate estimation work to baleen whales (right whales, blue whales, fin whales and humpback whales) and added different types of tags (i.e., time-depth recorders vs acoustic tags) to analyses of acoustic and auxiliary sensor data. The team refined methods and determined how proxy data (non-acoustic data such as depth) could be used to estimate cue rates. A paper describing the conditions under which one might be able to identify the tagged animal as the calling animal for baleen whales was submitted in 2024 with publication expected in 2025. Other published papers investigated caller identification in humpback whales (See Publications sidebar).

Tasks 4c and 4d, deep diver cue rate variability and investigating deep diver ICI, included considerable work on deep divers (including beaked whales and sperm whales) that were detected on bottom-mounted sensors. One of the work threads resulted in a manuscript published on geographic differences in echolocation clicks in Blainville's beaked whales and another manuscript on using ICI to infer about sperm whale demographics was published in 2024 (See Publications sidebar). This work hinted towards the possibility of using site-specific cue rates based on ICI patterns, a thread which will continue beyond the lifetime of the project.

An analysis of sperm whale click rates from towed arrays in Hawaii contributed to analyzing deep divers and was published during 2024 (See Publications sidebar). These are challenging data because unlike tag data they only provide partial information about cue production rates. The periods the animals are silent are unknown but fundamental to quantify cue rates. Nonetheless, this study provides new information about cue rates in an area for which there are no tagging studies yet.

Task 4e focused on evaluating how signal detector/classifiers might affect cue rate estimation. The team conducted simulations with data from Blainville's beaked whales and sperm whales to evaluate how different assumptions about deep diver beam patterns might impact the detection probability of echolocation clicks, with subsequent effects on density estimation. A manuscript was submitted to *The Journal of the Acoustical Society of America* in 2024, with publication anticipated in 2025.

Task 5, impacts of cue rate variability in density estimation (DE), used project data to analyze the potential effects of cue rate variability and sample size. Based on analysis conducted as part of task 4, the team showed that cue rates for a species can vary by geographic region. For sperm whales, the cue rate between different regions can vary by a factor of nearly 2. These data were used in simulation studies to show that applying a cue rate from one location to another can, in some cases, significantly over or underestimate density estimates. Analyses of the effect of cue rate sample size on the density estimate variance demonstrated that using more data resulted in lower variance in the density estimate.

The ACCURATE website, a key component of task 6 (dissemination and recommendations), is now complete and will be updated as additional references are identified and manuscripts are published. Although the ACCURATE project ended in December 2024, with a project of its magnitude there are products that will continue to become available. These include manuscripts with key outputs that were submitted in 2024 and will be published in 2025. One is a review manuscript on the

existing information about acoustic cue production rates for cetaceans, which is also associated with a reference list that includes all the cue rate-related references that were identified during the project. This list is also available at ACCURATE's website (accurate.st-andrews.ac.uk/project-objectives/task-1/list-of-references-containing-cue-rate-facts). A second is a manuscript analyzing the conditions under which the information on accelerometer channels on animal-borne tags (including DTAGs and Acousondes) can be used to inform caller identification, and hence cue rates, for a range of baleen whale species (fin, blue and southern right whales). There are other project areas for which manuscripts will be submitted in 2025.

> This project advanced the practical application of PAM-DE for Navy purposes.

The site also includes a comprehensive description of the project, the corresponding team, objectives, tasks and outputs (the manuscripts and outreach materials). Outreach materials include short videos of the different aspects to consider when doing PAM density estimation as well as a paper about it aimed at high school students. The ACCURATE website will provide a convenient hub for ACCURATE outputs in a single location accessible to the wider community for years to come.

Marine mammal density estimates are a critical element of the Navy's acoustic effects modeling, which supports at-sea compliance. Passive acoustic monitoring potentially offers a cost-effective method to generate density estimates for a wide range of species across Navy priority areas. Given the importance of cue rates for PAM density estimation, it is perhaps surprising how little was known—and remains unknown—about them. Absent cue rates, the routine implementation of PAM density estimation for cetaceans could be hindered. While PAM-DE might be the most effective way to survey deep divers, which rely on echolocation sounds to feed, thus ensuring somewhat less variable cue production rates, sound production rates for baleen whales remain quite challenging, with sounds often related to behavior and social contexts. By understanding cue rates and cue rate stability, this project advanced the practical application of PAM-DE for Navy purposes. The resulting repository of outputs and synthesized data will support future density estimation from passive acoustic monitoring.

About the Principal Investigator

Tiago A. Marques is a principal research fellow at the Centre for Research into Ecological and Environmental Modelling (CREEM), University of St Andrews, UK. Dr. Marques has been involved in several projects related to different aspects of statistical ecology, mostly with an emphasis on estimating animal abundance considering a large variety of methods and taxa and in particular leveraging on passive acoustic data. He earned his Ph.D. in statistics from the University of St Andrews, UK.

Key contributors: Len Thomas, Danielle Harris, Doug Gillespie, Popi Gkikopoulou and Peter Tyack (University of St Andrews, UK), Cormac Booth and Chloe Malinka (SMRU Consulting, University of St Andrews, UK), Ana Širović (Norwegian University of Science and Technology, Norway), Susan Parks (Syracuse University, USA), Erin Oleson and Karlina Merkens (NOAA NMFS Pacific Islands Fisheries Science Center, USA), Simone Bauman-Pickering (University of California San Diego, Scripps Institution of Oceanography, USA).

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Video

The ACCURATE Project, "Dealing with False Positives in Passive Acoustic Monitoring Estimation," YouTube video, 0:03:22. youtu.be/iMgls1yZChs.

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Frequency-dependent Underwater TTS in California Sea Lions

Principal Investigator: Ron Kastelein
Project Status: Completed, Project 45

NEED

N-0224-20: Frequency-dependent, Underwater, Temporary Threshold Shift in California Sea Lions

California sea lions commonly occur all along the western coast of the continental United States of America, including in Navy training and testing areas. Because there has been limited research on the susceptibility of California sea lion hearing to underwater sound, measuring temporary threshold shift (TTS), the Navy needs additional data to determine appropriate criteria for impact modeling. Data that characterize frequency-dependent underwater TTS across the frequency hearing range of California sea lions are particularly needed.

PROJECT

Navy acoustic impact assessments apply auditory weighting functions, similar to those used in assessing risk to human hearing, to predict the occurrence of TTS and permanent threshold shift (PTS) as functions of frequency. Threshold shift is one of the few direct measures of adverse effects of intense sound on hearing.

The associated weighting functions are mathematical functions that emphasize, or "weight," noise at different frequencies according to the listener's susceptibility to noise at that frequency. Direct measurements of TTS in representative marine mammal species—across a broad spectrum of sound frequencies—are needed to support the TTS/PTS thresholds and weighting function derivations.

This project tested how sounds of different frequencies may affect the underwater hearing of California sea lions (*Zalophus californianus*).

The original project goals were to

1. Establish underwater behavioral audiograms (hearing thresholds over the entire hearing frequency range of a species) for two more California sea lions and generate a generic underwater audiogram for California sea lions (At the project start, behavioral audiograms existed for only four animals, and some of the audiograms were masked.)
2. Determine the TTS susceptibility of hearing in California sea lions for sounds over their entire hearing range
3. Determine TTS onset sound exposure levels (SEL), a unit that incorporates both the sound level and the exposure duration, and TTS growth after exposure to sounds of various frequencies and SELs
4. Based on the information derived in items 1–3, construct equal TTS curves (one of which is the TTS onset curve), which can be used to produce an auditory weighting function for California sea lions
5. Determine which hearing frequency is most affected by each fatiguing sound frequency that sea lions are exposed to
6. Determine the recovery rate of hearing after the fatiguing sounds stop
7. Test the equal-energy hypothesis, which will investigate whether exposure to the same SEL, but composed of different sound pressure level (SPL) and exposure duration combinations, elicits the same TTS
8. Test the effect of duty cycle (percent of total time sound is being produced) on TTS (During pauses in a sound exposure, hearing can partly recover, reducing the threshold shift.)
9. Test how exposure measured with hydrophone grid measurements in a pool compares to

California sea lion at SEAMARCO.
Ron Kastelein

measuring exposure with a sound recording DTAG on a free-swimming sea lion in the same pool

10. Test whether exposure during free swimming elicits similar TTSs as the same exposure while the sea lion is stationary.

Two California sea lions, an adult female and a young male, with excellent hearing were tested within a pool complex designed for acoustic studies. The animals were exposed to the fatiguing sounds and their hearing was tested pre- and post-exposure. The fatiguing sounds were continuous 1/6th-octave noise bands, designed to create a homogenous sound field. Fatiguing sounds with the center frequencies 0.6, 1, 2, 4, 8, 16, 32 and 40 kHz were tested, with a one-hour exposure duration. This approach is similar to the methods this team used in previous LMR-funded studies of harbor seals (*Phoca vitulina*) and harbor porpoises (*Phocoena phocoena*), so results can be compared directly among the three species.

The equal-energy hypothesis study collected data to address potential effects of naval sonar that often operates for shorter durations and at higher sound levels. This study evaluated two frequencies (4 kHz and 8 kHz) with five exposure durations (10, 20, 40, 60 and 80 minutes) with five different SPLs; all duration and SPL combinations lead to the same SEL.

Six duty cycles have been tested: 2.5 (representative duty cycle of 53C sonar, ~4 kHz), 30, 40, 50, 60, 70, 80, 90 and 100 percent (the latter being the duty cycle of Continuous Active Sonar (CAS)). Assessing duty cycle effect on TTS for the 4 and 8 kHz exposures will provide data on both the closest frequency to the actual signal of interest (4 kHz) and the scalability of the TTS as a function of duty cycle at 8 kHz.

During 2020, data collection from fatiguing sound at three frequencies—2, 4 and 8 kHz—was completed. The 4 and 8 kHz tests also provided data for the equal-energy hypothesis study and the duty cycle study.

California sea lion wearing a harness with a DTAG.
Ron Kastelein

During 2021, data collection at three additional frequencies—0.6, 1 and 16 kHz—was completed, and 32 kHz testing was initiated. Animal training for a new task, to measure sound exposures with a sound recording DTAG on an animal, was also initiated. The goal of this task was to validate that the received levels of sound are comparable to what is estimated from prior calibration measurements in the pool with static hydrophones. This task required training the animal to voluntarily accept a harness to which the DTAG was attached. A task to determine the behavioral audiograms of the two California sea lions was also initiated during 2021.

During 2022, the project completed 32 and 40 kHz fatiguing sound exposures, and the data collection at very low frequencies for the audiograms. For the DTAG task, the team completed initial training needed for the animal to swim with a harness that carried the DTAG, enabling them to begin the DTAG data collection. They recorded all fatiguing sounds used in the TTS study twice with a tag on the animal. Each fatiguing sound is tested at three SPLs, and the acoustic body shadow for each fatiguing sound frequency was also measured. For this portion of the study, the animal was trained to wear the tag on its back and slowly turn around its body axis in front of the transducers that produced the same fatiguing sound as during the previous TTS studies. Additionally, two manuscripts were published in 2022 (see the Publications sidebar).

During 2023 the data collection using the DTAG was completed and two audiograms for California sea lions were completed. Two manuscripts were published in 2023 (see the Publications sidebar).

Work in 2024 focused on finalizing analysis of the results from the TTS elicited with 32 kHz and with 40 kHz fatiguing sounds and two manuscripts were submitted to a scientific journal for

publication. Both were accepted, with one published in 2024 and second being published in 2025. In addition, the data collected with the DTAG were published.

> This project provided insights into methods and equipment used during captive animal TTS studies.

An additional study conducted in 2024 was to test and compare different exposure conditions. In contrast to the previous sea lion TTS studies, in which the animals were swimming freely in the pool, a sea lion was trained to accept high-level sound exposure while stationary in front of an underwater loudspeaker for 15 minutes (see photo below). This behavior required significant training time and effort to accomplish. Previous TTS results that were collected when the sea lion was exposed to 4, 16 and 32 kHz fatiguing sounds while free swimming were compared to these new exposures to the same fatiguing sound frequencies when the animal was stationed at one location for 15 minutes. The two completed frequencies (4 and 32 kHz) showed that the SELs required to cause 6 dB TTS was the lowest when the two sea lions swam together in the pool during the exposures. Swimming alone or being stationary alone required a higher SEL to cause 6 dB TTS, presumably because the sea lion could self-mitigate. The final fatiguing sound frequency (16 kHz) will be completed in 2025, followed by a final publication detailing the differences found between exposure conditions.

So far, this project has produced data (a 6 dB TTS onset curve) that can be used to improve the weighting function of otariids (eared seals) in the Navy's acoustic effects analysis criteria. Results confirm the validity of the equal-energy hypothesis and provide new insights regarding the effect of duty cycle on TTS. The project provided two behavioral audiograms for California sea lions with threshold for very low frequencies, which have not been measured before in this species. In addition, a new generic audiogram for California sea lions was produced based on the data of the two study animals and similar data collected with an animal at Long Marine Lab in Santa Cruz, California. These products are directly applicable to all Navy compliance documents analyzing

California sea lion F01 at the exposure station with her ears just below the water surface and her nose just above the water surface. Except for short breaks to receive fish rewards, she voluntarily stationed herself like this for 15 minutes just in front of the underwater loudspeaker.
Ron Kastelein

acoustic effects of tonal sounds (e.g., sonars) and broadband sounds (e.g., explosions).

In addition to the hearing and TTS data, this project provided insights into methods and equipment used during captive animal TTS studies. The project is providing data that can be used to inform future improvement of the sound recording part of the DTAG (improve fidelity, reduce directionality, improve the housing), and offers insights into the frequency-dependent effect of body shielding on the sound level of the recordings by the DTAG. The project also provides insight into the potential variations in results of the different exposure methods used in TTS studies: free-swimming exposure (alone or with a pool mate) or stationary exposure. These types of insights inform future improvements of these studies.

About the Principal Investigator

Since 2002, Ron Kastelein, Ph.D. (University of Wageningen, Netherlands) has been director and owner of SEAMARCO (Sea Mammal Research Company, Inc.) in the Netherlands. SEAMARCO specializes in applied acoustic research and energetic studies with marine fauna (mammals, fish, turtles and invertebrates).

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Tethys Capability Enhancements

Principal Investigator: Marie Roch
Project Status: Completed, Project 46

NEED

N-0228-20: Marine Mammal Acoustic Software Application Enhancements

The Navy's need for efficient methods to analyze passive acoustic data continues to grow with the increasing amount of data collected by the Navy's Marine Species Monitoring Program. While publicly available acoustic analysis software applications have improved over the years, additional improvements are needed to enhance overall processing efficiency when identifying, characterizing and cataloging acoustic signals of interest.

PROJECT

This project enhanced Tethys, a set of standards and accompanying software created to organize, explore and archive data derived from acoustic monitoring devices for the purpose of better understanding marine mammal populations and assisting the Navy in assessing its impact on these animals. Tethys offers researchers a method to record these data in a manner that can be preserved over long time periods, which enables combining multiple studies to increase temporal and spatial coverage. Data can be accessed from a variety of platforms such as web browsers, MATLAB®, Java, Python and R. Tethys also provides easy access to oceanographic data, which represent a set of critical variables to be considered when attempting to understand animal behavior.

The prior version of Tethys was developed under a previous LMR project (Project 18, completed in 2020), co-funded by the Bureau of Ocean Energy Management (BOEM). That project built upon early work funded by the ONR MMB program. As the Tethys user group expanded, the need for additional enhancements to make the workbench more accessible became apparent.

This project worked to address the following key enhancements. Each is summarized below with its purpose and work completed under LMR funding. Additional work funded by BOEM to integrate Tethys with PAMGuard, a widely used software platform for detection, classification, and localization, is well underway and will continue through 2025.

1. **Technology updates to ensure security and prevent obsolescence**

   This task was largely completed during 2021. There were two primary components targeted for upgrade. First, the server code was migrated to the most recent version of Python (Python 3). The team identified existing library packages that are no longer supported under the new version, made minor code changes to the core code base, and reengineered functionality to support the packages.

   The second major direction of the code update was to replace the underlying data storage technology and upgrade the database engine to the most recent version of Oracle's Berkeley extended markup language database (Berkeley DBXML).

   Additional changes to the system provide high-performance indices that enhance scalability. In 2022, the team reengineered query construction to take advantage of these new indices, resulting in query times that were frequently reduced by up to two orders of magnitude. In addition, the project team implemented a caching scheme that reduced the time for commonly used complex queries to milliseconds. As part of the query system overhaul, the team reengineered the system for generating queries from user selection criteria. These changes made it easier to support queries from additional clients such as the R

programming language client that was first released in 2024.

Some additional internal improvements include the development of server-computed sunrise/sunset times, which take advantage of parallelism available in modern computers. Parallelism lets the user compute solar rise/sets at a rate greater than 11,000 times faster than real-time. As an example, more than a decade's worth of rise and set times can be computed in about 20 seconds as opposed to the several minutes of computation time required on a single processor. Coupled with a new scheme for retaining the results of frequently requested queries and earlier work that introduced improved database indices, speed has been improved in most cases by an order of magnitude or two depending on the operation.

2. **A drag-and-drop data import interface**

Importing data into Tethys from detection, classification and localization (DCL) software requires matching data fields produced by DCL software to the standardized field names used in Tethys. At the start of this project, data import required that users be able to map their data to Tethys fields via a text-based specification. While conceptually simple, users frequently had errors in these documents and requested simpler ways to incorporate their data into Tethys.

During 2023, the team developed a web-based interface to let users drag and drop between Tethys fields and their data sourced from a database, spreadsheet or text file (Figure 1). Displays let users know which fields remain to be mapped and provide options for combining

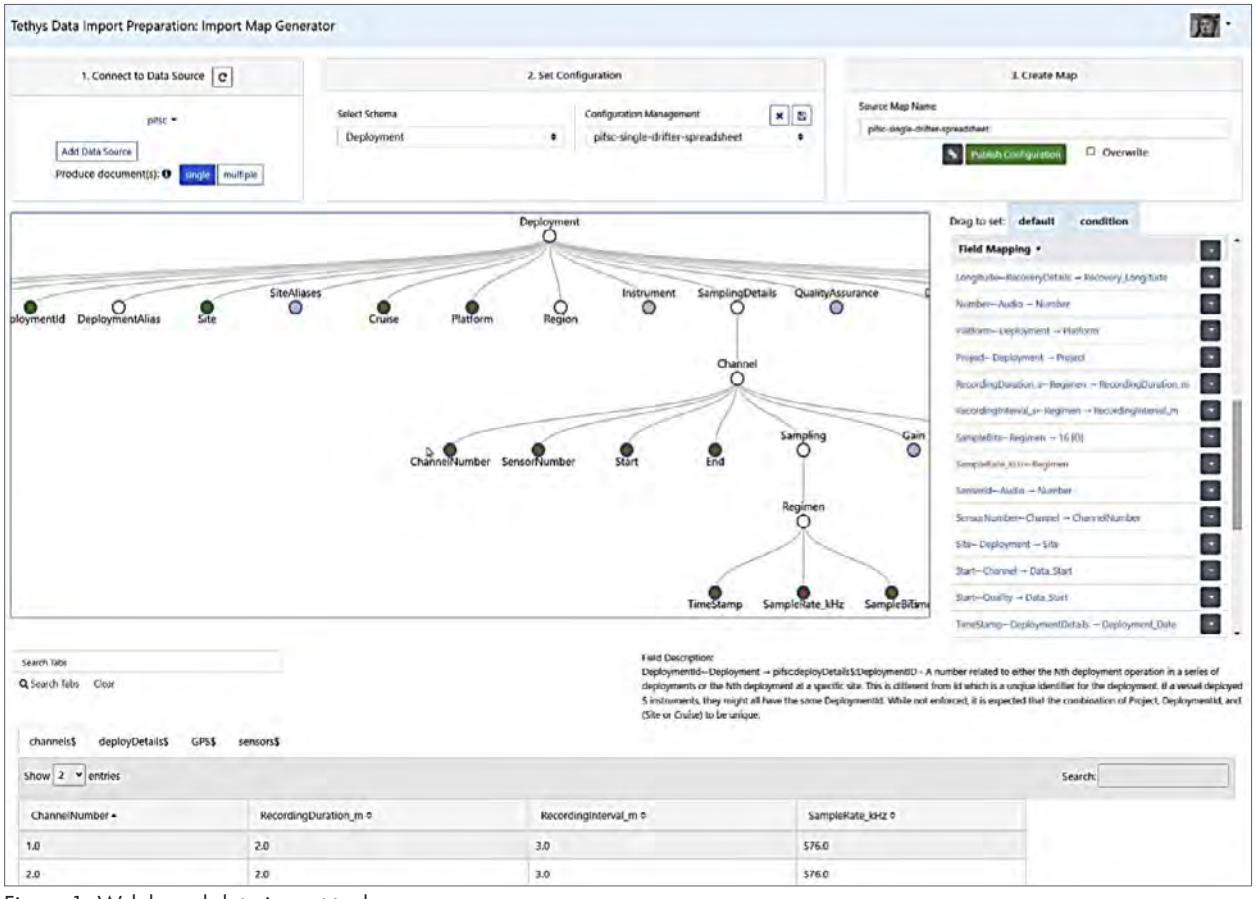


Figure 1: Web-based data import tool.

and modifying fields. Once fields have been matched, the specification is published as a data map and can be used to import user data that have the same structure. This process reduces the opportunities for users to make errors in the specification for mapping between user-defined fields and Tethys's standardized fields. Additional enhancements were made in 2024, permitting users to combine multiple fields, add simple conditions, and specify simple computations on their data such as unit conversion. A second web interface was developed for importing data using a published data map. Combined, these two new interfaces provide a streamlined way to import data into Tethys.

3. **An advanced mapping interface**

   The project migrated from the current proprietary Google Maps application programming interface to the open-source Leaflet map library. During 2021 and 2022, the team began designing a new Leaflet interface and leveraged current oceanographic data retrieval capabilities to generate mapping layers. The interface provides multiple views of data, and the user can now easily see instrument deployments (including the tracks of mobile instruments such as gliders and towed arrays), as well as when and where analysis effort has been made for specific species. In 2023 the team added new filters and data displays such as the ability to display results in local time and view lunar, diel and twilight data (Figure 2).

4. **A beta-user program**

   The Tethys team conducted a beta-user workshop in 2022 to introduce users to new developments and have them identify areas for improvement. Nine users from multiple agencies, including Navy, NOAA and academia participated. During the workshop, participants were able to enter a portion of their data into the database, demonstrating the utility of Tethys for their data. The participants offered valuable insights on additional development needed to further improve the utility of Tethys to a larger audience. Two specific feedback items resulted in additional documentation addressing user needs and improvements to the advanced mapping interface.

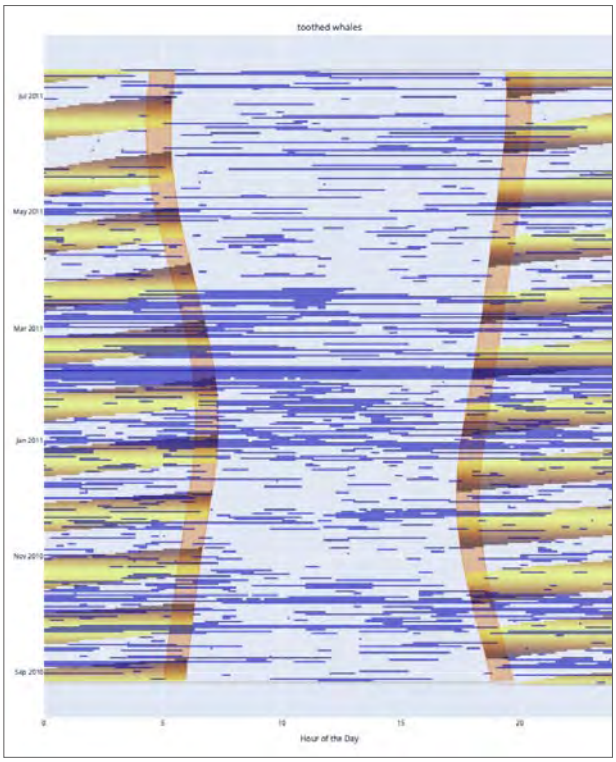


Figure 2: Occurrence of toothed whale echolocation (blue) on a daily cycle over a roughly one-year period near the Jacksonville Undersea Warfare Training Ranges (USWTR).

5. **Integration of Tethys and PAMGuard**

   In a synergistic project sponsored by BOEM, the team is now working with Dr. Douglas Gillespie at The University of St Andrews to develop the ability for PAMGuard, a widely used DCL tool, to automatically publish data to Tethys. Initial versions of this functionality were sent to the project steering committee and participants in a one-day satellite workshop in 2024. Revised versions will be used in two four-day workshops to be conducted in 2025, targeting users of interest to the Navy

and BOEM. This work to integrate PAMGuard and Tethys will be beneficial to the Navy and the general user audience.

This project helps the Navy retain the long-term information about marine mammal species needed for Navy monitoring and mitigation plans.

6. **Standards Committee**

   The project leads the Acoustical Society of America/American National Standards Institute (ASA/ANSI) working group (S3-SC1-WG7) for the standardized representation of bioacoustic data. The committee brings together bioacousticians from industry, government and academia to focus on defining which data must be archived to provide scientifically useful long-term retention of passive acoustic metadata. The starting point for the standard was the community standards developed for the Tethys project. In 2024, the standards committee reviewed a first draft of the standard and a how-to guide (recommended by ASA/ANSI) that defines why and how the standard is used. Revisions are underway and the standard will be submitted for consideration by the American National Standards Institute in 2025. The standard has been used by government projects such as the National Center for Environmental Information's Passive Acoustic Data Portal and NOAA's Northeast Fisheries Science Center Passive Acoustic Monitoring Map.

Tethys 3, the third version of the software, released in 2023, provides a reference implementation of the standards. Highlights of the release include improved speed, incorporation of changes from our ANSI committee on standardizing metadata, extensive work on making it easier to incorporate new data into the database, and further development of the advanced mapping interface. Responding to feedback from the 2022 beta-user workshop, the team added additional information to error messages, updated user interfaces and completed documentation for the new features. Additional features such as PAMGuard support were incorporated into the 3.1 release in 2024.

This project helps the Navy retain the long-term information about marine mammal species needed for Navy monitoring and mitigation plans and currently used in producing some of the monitoring reports provided to the Navy's Pacific Fleet. As previous research has demonstrated, Tethys's data preservation and the ability to reuse data have expanded the scope of science and policy-based questions that can be asked. Retaining data from large-scale spatial and temporal studies provides clear benefits for advancing science, enhancing the Navy's capabilities for monitoring cetaceans, and preparing impact assessments.

About the Principal Investigator

Marie A. Roch is a professor of computer science at San Diego State University and has over two decades of experience working with marine bioacoustics. Dr. Roch is internationally recognized for her machine learning work on classifying marine mammal vocalizations. The Tethys project arose from a need to ensure that the outputs of marine mammal detection, classification and localization efforts could be preserved to enable the study of long-term trends and impacts.

Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds

Principal Investigator: Dorian Houser
Project Status: Completed, Project 47

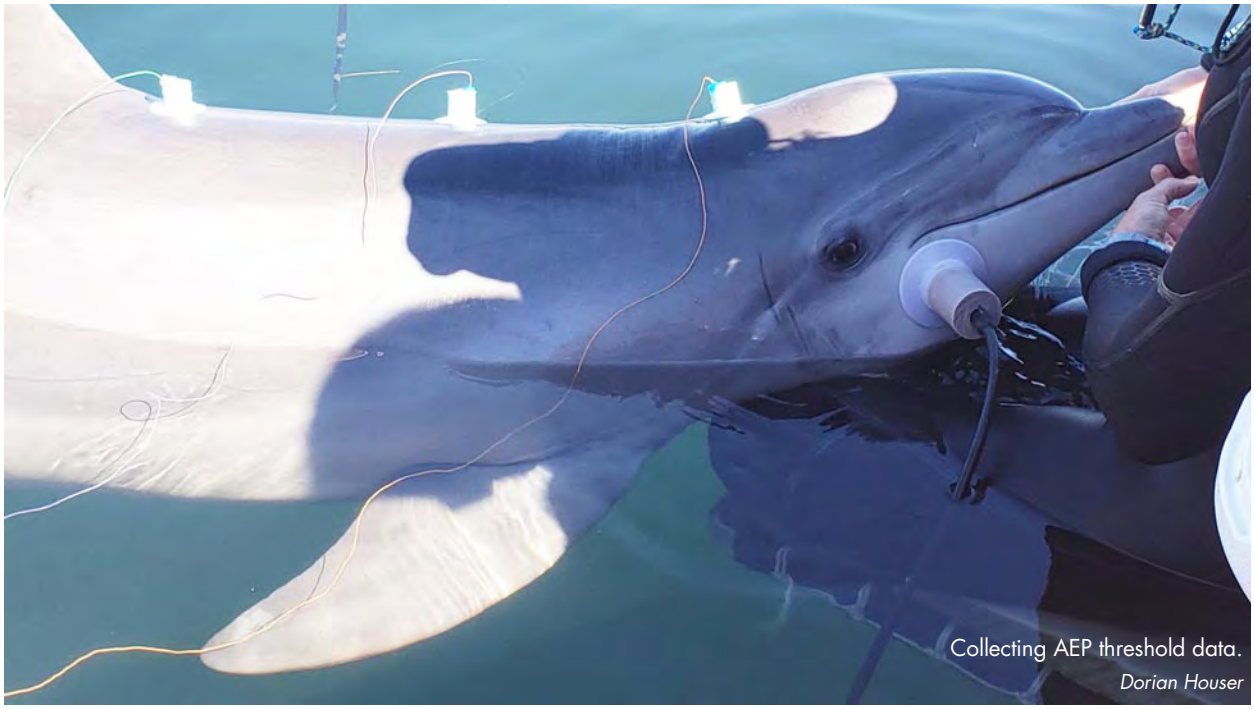
NEED

N-0237-21: Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds

Auditory Evoked Potential (AEP) methods are often used to study hearing capability in marine mammals and have expanded the available audiogram data for both captive and stranded animals. AEPs will continue to be the primary means by which sample sizes of audiograms increase because they are easier to implement than behavioral hearing threshold methods, and they can be used in untrained or stranded animals. However, due to the frequency-dependent elevation of AEP thresholds over behavioral hearing thresholds, AEPs are currently only used for defining species' upper-frequency limit of hearing. Thus, the Navy currently uses only behavioral hearing thresholds for assessing absolute hearing sensitivity. The ability to study and account for the differences in the two methods might enable AEP audiograms to be adjusted and made comparable to audiograms obtained from behavioral audiogram approaches. The Navy would benefit from a standardized approach by which AEP hearing thresholds could be adjusted and compared to behavioral thresholds. This would make a greater number of AEP audiograms available for use in weighting function development and other Navy at-sea compliance efforts, broadening the application of AEP results in future criteria development.

PROJECT

This project worked to empirically determine relationships between behavioral and AEP hearing thresholds in small odontocetes to make behaviorally "equivalent" AEP audiograms. Although frequency-specific differences between behavioral and AEP audiograms have been previously explored in the bottlenose dolphin, a systematic evaluation of the differences between approaches has not been completed. By measuring behavioral and AEP



Collecting AEP threshold data.
Dorian Houser

Dolphin performing AEP.
Dorian Houser

hearing thresholds in the same individuals across the range of hearing, the team collected data on the frequency-dependent relationship between behavioral and AEP thresholds and how the relationships changed as a function of the particular AEP test method employed. Results will be applied to existing AEP audiograms to increase the data available for the development of auditory weighting functions, which will allow AEP audiograms of untested small odontocetes to be converted to a form usable by the U.S. Navy in at-sea compliance.

The team's initial focus was on determining AEP threshold "equivalence" corrections for behavioral threshold prediction. Five bottlenose dolphins of the United States Navy Marine Mammal Program were tested to determine the frequency-specific offsets between behavioral and AEP hearing thresholds. Each day, after a hearing threshold was determined behaviorally with the dolphin submerged, AEP thresholds were obtained using four different methods: dolphins partially submerged and using either tone pips or sinusoidal amplitude modulated (SAM) tones for testing, and with dolphins out of the water using either tone pips or SAM tones. In all the AEP tests, a contact transducer, or "jawphone," was attached to the jaw and used to deliver sounds to the dolphins.

The AEP test scenarios replicated approaches commonly used with stranded and rehabilitating odontocetes. The methods allowed the variability

in each AEP method to be determined. Subsequently, the AEP thresholds obtained under each test condition were compared to the behavioral threshold collected on the same day to determine frequency-specific differences between the AEP and behavioral results. The differences between the behavioral and AEP thresholds were used to adjust the AEP thresholds such that they become effectively behaviorally equivalent.

> This work will substantially increase the currently limited amount of data available for developing auditory weighting functions.

Based on the results, equivalence corrections were applied to previously acquired AEP audiograms in novel or seldom tested odontocete species to produce behaviorally equivalent audiograms for those species. The same corrections can be applied to novel species of mid-sized odontocete tested in the future.

Data collection for the dolphins was completed in 2022 and data analysis began. The team began comparing AEP thresholds to behavioral thresholds for both tone pips and SAM tones in air and underwater for frequencies ranging from 11.3 kHz to 128 kHz. Other work initiated in 2022 included gathering source data for the equivalence correction.

In 2023 and 2024, the equivalence analysis was completed for all the test conditions and behaviorally equivalent audiograms were created for several species for which no behavioral audiograms exist. A manuscript describing the results of the study was drafted and submitted in late 2024 to *The Journal of the Acoustical Society of America,* with publication anticipated in early 2025. A draft report on the equivalence procedure was completed in 2024 with the final version expected in early 2025. Additional data are still being acquired for species for which behavioral equivalence might be obtained.

There will be ongoing coordination with the National Marine Fisheries Service and U.S. Navy regarding the potential implementation of behaviorally equivalent audiograms in Navy analyses. The behaviorally equivalent audiograms will bolster weighting function design and add defensibility to the U.S. Navy's audiogram-based approach to predicting marine mammal auditory weighting functions. This work will substantially increase the currently limited amount of data available for developing auditory weighting functions and will allow AEP audiograms of untested small odontocetes to be corrected to a form the Navy will be able to use in its at-sea compliance analysis.

About the Principal Investigator

Dorian Houser is Director of Conservation Biology at the National Marine Mammal Foundation (NMMF). He has spent over two decades in the study of how anthropogenic sound affects marine mammals and served as the chair of the American National Standards Institute/Acoustical Society of America (ANSI/ASA) committee on Animal Bioacoustics (S3/SC1) from 2013 to 2024. Dr. Houser chaired the working group that led the development of the standard ANSI/ASA S3/SC1.6 2018, *Procedure for Determining Audiograms in Toothed Whales through Evoked Potential Methods*. He earned his Ph.D. in biology from the University of California Santa Cruz.

Co-PIs are Dr. Jason Mulsow (NMMF) and Dr. James Finneran (U.S. Navy Marine Mammal Program).

Dependence of TTS on Exposure Duration During Simulated Continuous Active Sonar: Examining the Equal-energy Hypothesis for Long-duration Exposures

Principal Investigator: Jason Mulsow
Project Status: Completed, Project 51

NEED

N-0238-21: Understanding Marine Mammal Hearing and Behavioral Response to Continuously Active Sonar

Results from previous behavioral response studies have indicated that both the type and the duration of Navy sonar signals may play a role in observed responses in marine mammals. As sonar technologies change, the Navy needs new information on the effects of new types of sonar on marine mammal hearing and behavior. Continuous active sonar is a type that can operate at lower energy levels than traditional pulsed signals, but operates at higher duty cycles (i.e., transmits for a longer time). In 2017, LMR began investing in studying and collecting data on behavioral response to continuous active sonar as part of the third phase of the Sea Mammals and Sonar Safety (3S3) project (LMR Project 29). The Navy needs more information to further understand the effects of continuous active sonar on marine mammals, particularly with additional marine mammal species.

PROJECT

This project measured temporary threshold shift (TTS) in the bottlenose dolphin using auditory evoked potential (AEP) and behavioral threshold measurements for longer duration signal exposure with signal qualities simulating continuous active sonar (CAS). The intent was to determine if equal energy exposures result in equal TTS, independent of exposure duration. In current Navy noise effects analyses, estimates of TTS onset are based on the equal-energy hypothesis, which states that exposures of equal sound exposure levels (SEL) result in equal TTS. Therefore, the short, high sound pressure levels (SPLs) of pulsed sonar are considered equivalent—in terms of TTS—to lower SPL continuous exposures that have the same cumulative SEL. However, while source and received SPLs of CAS may be lower than those of pulsed sonars, accumulated SEL may be high due to the high duty cycles of CAS, as fewer quiet periods will be present during which SEL does not accumulate.

The project goals were to

1. Determine the extent to which the equal energy hypothesis can be used to predict TTS for exposures up to 60 minutes
2. Determine if frequency modulation (FM) common to CAS reduces TTS effects relative to continuous wave (CW) tones with equal SEL.

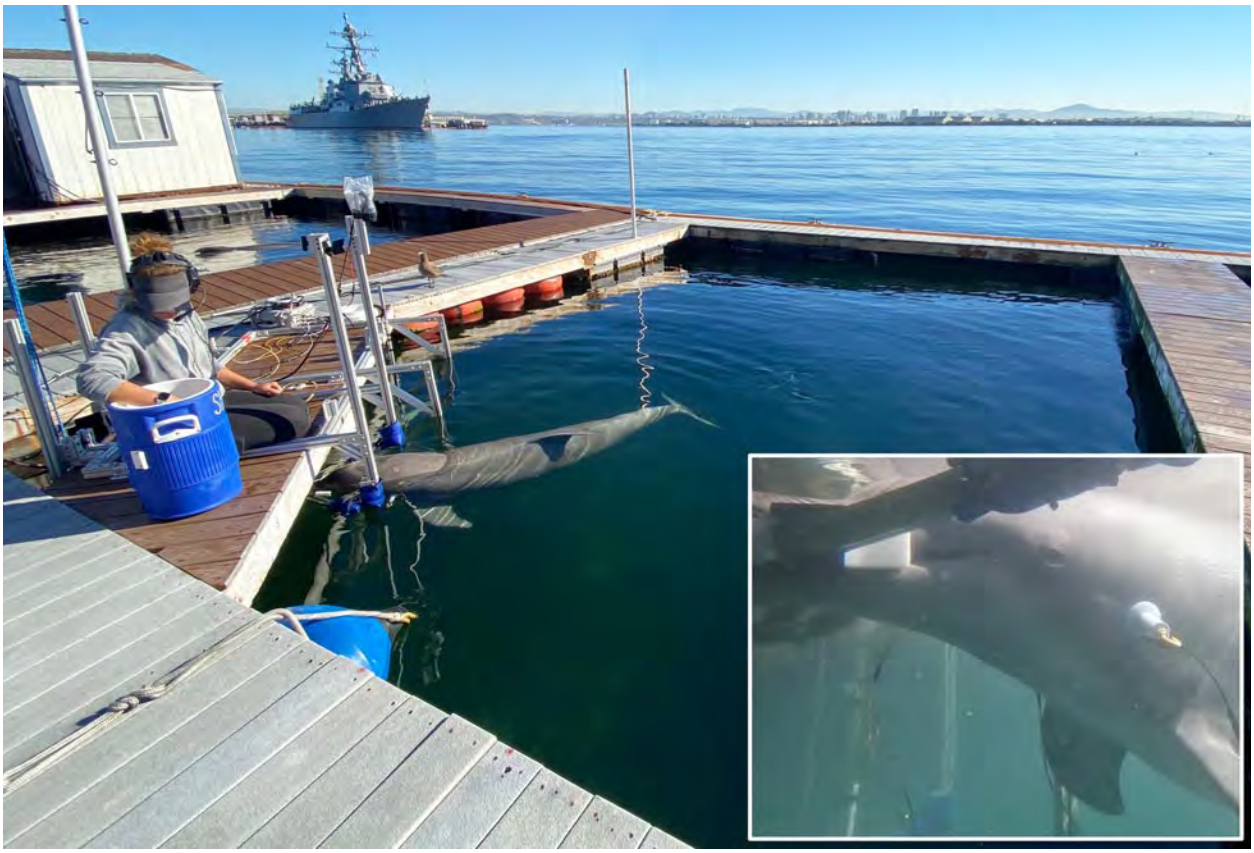
The research team collected hearing data from two bottlenose dolphins at both a frequency representative of CAS (3 kHz) and a frequency closer to the region of best hearing sensitivity (28 kHz). The researchers used rapid behavioral and AEP procedures for determining hearing thresholds so that thresholds could be measured on a short time scale relative to hearing recovery after 28-kHz noise exposure.

The fatiguing stimuli used to induce TTS were both CW tones and FM tones with bandwidths characteristic of CAS. It was expected that TTS effects would be smaller than those observed for CW tones, which have noise energy distributed over a larger area in the frequency map in the inner ear. The 28-kHz stimulus was a one-octave hyperbolic FM sweep based on simulated CAS used by the LMR-funded 3S experiments (previously completed 3S3, Project 29; new start 3S4, Project 64, page 70), but frequency-shifted to match the region of best sensitivity in the dolphin's hearing curve. The 3-kHz stimulus was a narrower-band one-third octave linear FM sweep based on the actual characteristics of U.S. Navy sonar.

Intermittent hearing tests were conducted following the noise exposures, both to track the hearing recovery rate with time post-exposure and to ensure complete recovery of hearing threshold before subsequent exposures, minimizing the chance of inducing a permanent threshold shift. The health and welfare of the dolphins was monitored by the attending veterinarians and animal care staff at the Naval Information Warfare Center, Pacific over the course of the study.

The completion of testing at 28 kHz was originally planned for 2022 but was delayed because a Navy dredging project in the testing area required temporarily relocating the animals in November 2022. Noise exposures at 28 kHz restarted in May 2023 and were completed four months later in August, resulting in a total of 87 exposures (and 44 control sessions) for two dolphin subjects. Behavioral TTS onset SELs for the 28-kHz simulated CAS were similar to or higher than those for existing Navy TTS criteria in delphinids (on the order of 180–190 dB re 1 µPa2s) and supported the use of the equal-energy hypothesis in estimating TTS resulting from exposures that vary in duration and level. The CW tone did not appear to be more effective in inducing TTS, despite initial predictions to the contrary. Threshold shifts at 28 kHz measured using AEP methods did not show any consistent correlation with behavioral data. This result contrasts with some previous studies that have conducted AEP measurements of TTS in toothed whales and found onset SELs similar to those obtained with behavioral methods.

Testing with the 3-kHz simulated CAS waveform began in September 2023 and was completed in October 2024. In total, 74 noise exposure sessions



A bottlenose dolphin at the U.S. Navy Marine Mammal Program positions on the noise exposure station. Inset: Noise levels are continuously measured during experimental sessions using suction-cup hydrophones placed on both sides of the dolphin's head.

(and 112 control sessions) were conducted with two additional dolphins. The TTS onset SELs for both subjects were quite similar at 3 kHz (on the order of 200 dB re 1 µPa2s) and confirmed that higher SELs are required to induce TTS as compared to 28 kHz. This finding is consistent with the less sensitive hearing (higher thresholds) below approximately 10 kHz in toothed whales. Like the previous measurements conducted at 28 kHz, the data at 3 kHz supported the validity of the equal-energy hypothesis for estimating TTS from CAS exposures up to 1 hour in duration.

This work is directly applicable to the Navy's at-sea compliance process and aids in obtaining permits to conduct uninterrupted training and testing activities.

The study's findings were presented in 2022 and 2023 at meetings of the Acoustical Society of America, and a manuscript summarizing all work was submitted to *The Journal of the Acoustical Society of America* in December 2024. The data and conclusions will be used to support updating the Navy's acoustic criteria and thresholds for estimating TTS exposures for high-frequency toothed whales from at-sea training and testing activities that involve CAS signals. The data will also be used to refine the Navy's acoustic criteria and thresholds for estimating TTS exposures for other marine mammal species for which TTS data are not available (e.g., baleen whales). This work is directly applicable to the Navy's at-sea compliance process and aids in obtaining permits to conduct uninterrupted training and testing activities for different signal types, such as CAS.

About the Principal Investigator

Jason Mulsow is a scientist at the U.S. Navy Marine Mammal Program, Naval Information Warfare Center Pacific in San Diego, CA. His research uses behavioral and electrophysiological methods to examine sound reception and production in cetaceans and pinnipeds. He has worked on examining the effects of noise on marine mammals and in the development of criteria for estimating and mitigating such effects. Dr. Mulsow earned his Ph.D. in ocean sciences at the University of California Santa Cruz.

Co-PIs are Dr. Alyssa Accomando and Dr. James J. Finneran (Naval Information Warfare Center, Pacific).

Publications

Mulsow, J., Pardini, M.R., Schlundt, C.E., Accomando, A.W. and Finneran, J.J. (in review). Temporary threshold shift to simulated continuous active sonar in bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America*.

Pardini, M.R., Mulsow, J., Schlundt, C., Accomando, A. and Finneran, J. (2023). Bottlenose dolphin (*Tursiops truncatus*) temporary threshold shift in response to frequency-modulated and pure-tone exposures centered at 28 kHz. *The Journal of the Acoustical Society of America*, 154, A18. DOI 10.1121/10.0022645.

Mulsow, J., Schlundt, C.E., Accomando, A.W. and Finneran, J.J. (2022). Temporary threshold shift from continuous 20–40 kHz hyperbolic upsweeps in bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America*, 152(4):A108. DOI 10.1121/10.0015705.

Using Passive Acoustic Tracks from a Navy Array to Study Large Whale Behavior in the North Atlantic

Principal Investigator: Regina Guazzo
Project Status: Completed, Project 65

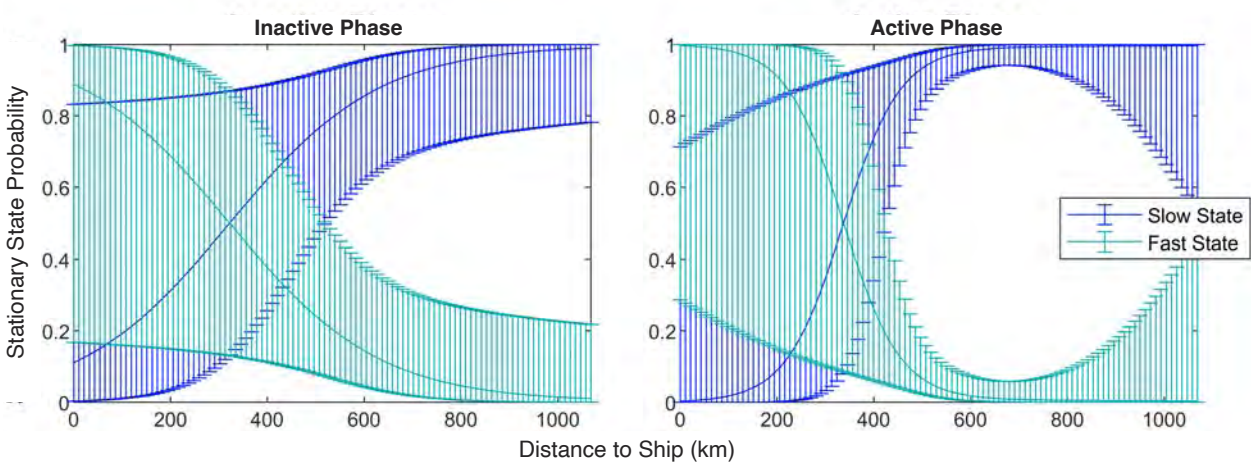
NEED

N-0260-22: Research that Pertains to the LMR Program Investment Area *Data Processing and Analysis Tools*

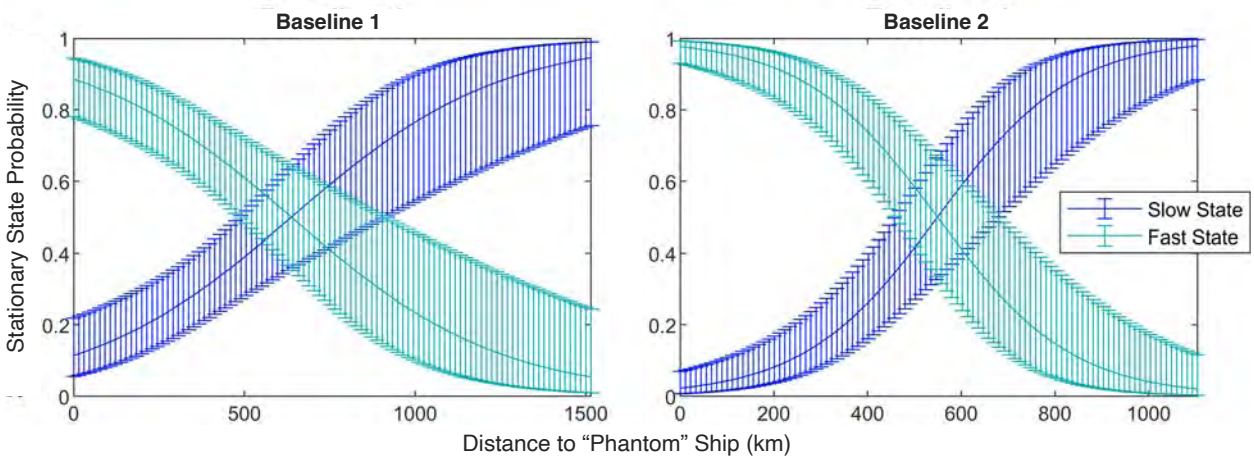
The Navy is interested in developing methods to improve the efficiency of processing and analyzing marine species data and providing cost effective solutions to enhance marine species monitoring capabilities (e.g., detection and classification algorithms, passive acoustic monitoring automated processing tools, statistical methods).

PROJECT

This project demonstrated the utility of the Navy's passive acoustic marine mammal monitoring data system, M3. The M3 dataset contains 20 years of passive acoustic monitoring and tracking data collected from bottom-mounted sensors. This work expanded on a project originally funded by the Department of Defense Science, Mathematics, and Research for Transformation (SMART) Supporting Effective Educator Development (SEED) grant program using M3 data to analyze behavioral responses to seismic surveys.



The probability of a 30-min observation of a blue whale track being in the Slow State or Fast State based on the distance to the seismic survey ship and the phase of the survey.



The probability of a 30-min observation of a blue whale track being in the Slow State or Fast State based on the distance to the "Phantom" Ship, which is at the middle of the seismic survey during the same time of year but during two non-survey years (Baseline 1 and 2).

Guazzo et al., In Prep

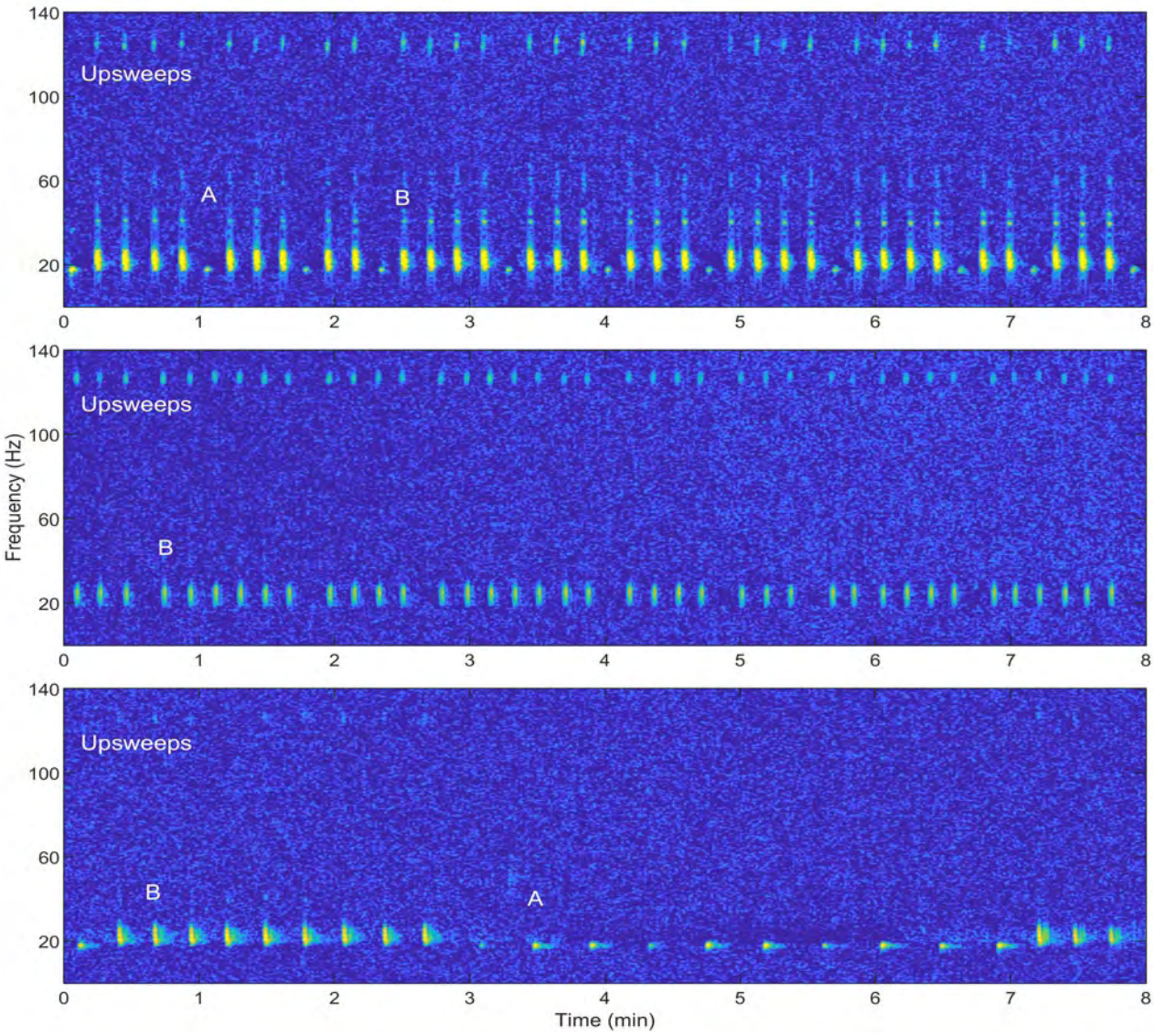
This project focused on two tasks:

1. **Analyze data for behavioral response to seismic surveys for whale species present (blue, sei, fin, humpback and sperm whales)**

   Passive acoustic tracks in the vicinity of seismic survey vessels and baseline data collected during the same time of year as one of the surveys but in different years were segmented into regular intervals which were categorized into a behavioral state based on speed: fast or slow. The behavioral state was modeled as a function of time of day, relative position of the seismic vessel and seismic phase (active or inactive). These models were used to test the hypothesis that whale behavior changes during a seismic survey.

2. **Process previously collected recordings of fin whale tracks to automatically detect every fin whale note**

   The resulting fin whale dataset was manually validated to identify any missing or false notes. After adapting the tools previously developed for analyzing fin whale tracks at the Navy's Pacific Missile Range Facility, the Atlantic data



Segments from three example fin whale songs in the North Atlantic with the three note types labeled.
Guazzo et al., 2024

were analyzed for fin whale song patterns and to quantify cue rates. (These tools were developed under an LMR partnership project that was completed in 2019, Developing Tools for Acoustic-only Behavioral Response Studies at Navy Instrumented Ranges.)

> The project helped to refine methods needed to make the passive acoustic monitoring data housed in the M3 system more available for use by Navy personnel.

During 2022, the project lead focused on Task 1, including testing the statistical modeling approach by using data from one seismic survey as part of the SMART SEED grant program. The work then focused on generalizing and repeating the tested methods using data from other seismic surveys and preparing a manuscript on whale behavior during a seismic survey.

Work in 2023 focused on Task 2, analyzing song patterns from 119 fin whale recordings in the North Atlantic over 10 years (2013–2023). A manuscript was submitted to *Frontiers in Marine Science* describing the results of this work.

The fin whale song manuscript was published in 2024 (see Publications sidebar). The project lead then returned to Task 1 and completed the analysis and wrote a manuscript detailing the results of whale behavior during a single seismic survey compared to baseline behavior.

Project outcomes will include a process for securely handling and analyzing data from the M3 system. An additional manuscript comparing the observed behavioral responses of large whales to a seismic survey with behavior during periods with no survey was in preparation at the close of 2024.

The project helped to refine methods needed to make the passive acoustic monitoring data housed in the M3 system more available for use by Navy personnel to monitor whale presence and abundance in the North Atlantic. Characterizing fin whale cue rates and song patterns also contributes to improved analysis of acoustic data needed for Navy at-sea compliance assessments. Analyzing behavioral response to a seismic survey vessel provides a framework that can be used for future behavioral response studies using this system.

About the Principal Investigator

Regina Guazzo works with the Whale Acoustics Reconnaissance Project (WARP) at the Naval Information Warfare Center Pacific (NIWC Pacific). Dr. Guazzo earned her Ph.D. in oceanography from Scripps Institution of Oceanography at University of California San Diego. Her work at WARP focuses on using passive acoustic monitoring data from Navy hydrophone arrays to characterize marine mammal behavior.

Publication

Guazzo, R.A., Stevenson, D.L., Edell, M.K., Gagnon, G.J. and Helble, T.A. (2024). A decade of change and stability for fin whale song in the North Atlantic. *Frontiers in Marine Science*, 11. DOI 10.3389/fmars.2024.1278068.

Passive Acoustic Monitoring Access Network: Advancing Data Management and Cyberinfrastructure Solutions for a Big Data Problem

Principal Investigator: Carrie Wall
Project Status: Completed, Project 66

NEED

N-260-22: Research that Pertains to the LMR Program Investment Area *Standards and Metrics*

The Navy is interested in establishing interagency and scientific community standards and metrics for data collection, management and analysis. This facilitates information exchange, which is necessary to harness the capabilities of aggregated data.

PROJECT

This project successfully piloted a community-focused national cyberinfrastructure capability for passive acoustic monitoring (PAM) data, technology, data archiving standards and best practices. It has enabled improved, scalable and sustainable accessibility to large quantities of PAM data and provided applications for using the data for resource management and science. The project was jointly funded by the Navy (Living Marine Resources and Office of Naval Research), NOAA and BOEM.

The project established a Sound Cooperative (SoundCoop), also known as the Passive Acoustic Monitoring National Cyberinfrastructure Center, at the National Centers for Environmental Information (NCEI). The SoundCoop promotes the use of centralized assets where appropriate, builds toward a larger group of stakeholders, and coordinates further development opportunities to avoid duplication and divergent products. It works with NOAA's Data Management and Cyberinfrastructure (DMAC) system and has enhanced current architecture to manage and distribute passive acoustic data. The NCEI, with its established partnerships and proven results, is well positioned to archive key data assets and support common metric extraction from long time-series datasets for both the archived assets and a broader community of data holders.

The SoundCoop incorporated previously collected passive acoustic datasets from regional to national scale monitoring programs conducted within and outside of the U.S., with a focus on large federally funded project repositories prioritized by BOEM, Navy and NOAA. The SoundCoop offers the organizational setting to support connected repositories that leverage common cyberinfrastructure components and data management approaches, rather

Figure 1: NCEI Passive Acoustic Data Archive Map Viewer displaying archived Navy-funded datasets

than being a centralized repository for all the nation's PAM data collections. The connected repositories, operated with common infrastructure, are benefitting bioacoustic research and management.

This effort involved a wide range of interested parties and stepwise expansion. There were four main objectives.

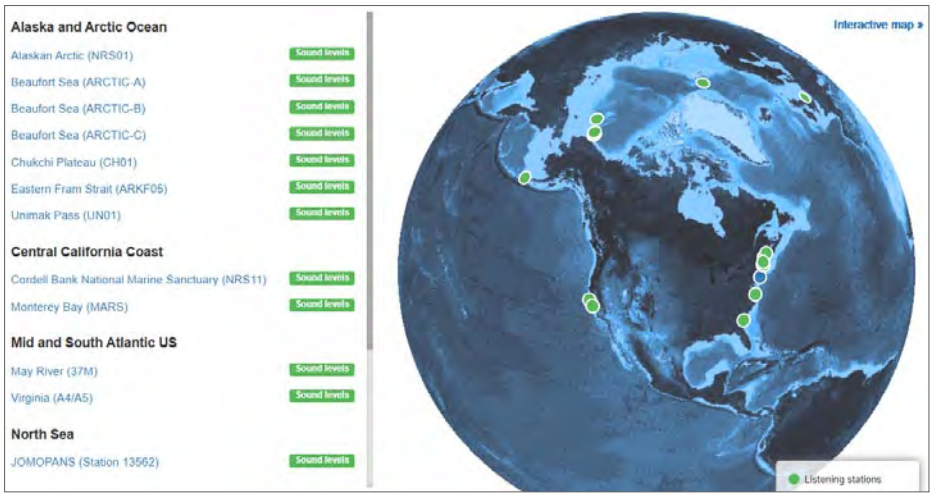


Figure 2: SoundCoop interactive portal.

1. **Stand up advisory committee and convene scoping workshops in Years 1, 2 and 3**
   Focus on community discussions to inventory existing PAM data collections, identify gaps in access and infrastructure, and further institutionalize existing standards and best practices for processing acoustic data.

2. **Provide cyberinfrastructure capabilities for Passive Acoustic Monitoring National Cyberinfrastructure Center (SoundCoop)**
   Advance capabilities and capacity by bringing together researchers across geographically distributed laboratories, universities and agencies guided by an advisory team.

3. **Plan for, add and curate PAM datasets and integrate with oceanographic data**
   Integrate oceanographic data to serve as a holistic PAM visualization platform.

4. **Develop a plan to support technology transfer**
   Support future PAM projects so that they may be interoperable with existing datasets available through the SoundCoop and thereby contribute a lasting impact.

During the project's first year with LMR funding, 2023, the team developed streamlined workflows for packaging data to be submitted to the archive, expanded the content in the NCEI Passive Acoustic Data Archive by 160 terabytes (TB) and developed a beta version of the SoundCoop portal to provide greater functionality for users seeking to access the archive data. The 2023 SoundCoop scoping workshop demonstrated the significant progress made to date and identified areas for focus during 2024.

Efforts in 2024 focused on the NCEI Passive Acoustic Data Archive team activities, which include launching the Passive Acoustic Collection Engine (PACE), a new scalable toolkit for data providers to prepare numerous datasets simultaneously for submission to NCEI. Working closely with Dr. Kaitlin Frasier (see LMR Project 60, page 86), the team archived numerous Navy-funded passive acoustic datasets (Figure 1).

Through collaborative efforts with data providers, the NCEI Passive Acoustic Data Archive grew by another 114 TB in 2024, reaching a total of 626 TB. This is an extensive dataset, spanning decades, that is now available for download.

The SoundCoop portal (accessed on the SoundCoop website: soundcoop.portal.axds.co), developed by Axiom Data Science (Figure 2), evolved from beta to fully functioning during 2024. Portal users now can interactively visualize hybrid

millidecade spectra and integrate wind speed and wave height from nearby oceanographic sensors. Specifically, users can select which sensor they want to use based on spatial proximity to the recording site, visualize the time series for wind speed and wave height that aligns with the acoustic timeseries, and visualize power spectral plots contextualized by categories of wind speed and wave height.

> This project enables the Navy to leverage an existing national archive infrastructure, which provides cost savings and efficiencies.

The project's GitHub repository (github.com/ioos/soundcoop) also was launched in 2024. The repository includes automated workflows that leverage Python libraries to access sound level metrics in Network Common Data Form (NetCDF) from the Google Cloud Platform (GCP), Amazon Web Services (AWS) and Axiom Data Science's Research Workspace. This builds on an interactive online notebook capability—Jupyter Notebook—that was developed in 2023 to share the workflow steps. It includes documentation on how to run the notebooks to reach both technical and more novice audiences. The repository makes these workflows publicly available as a community resource.

The project's website, also completed in 2024, provides a centralized page with information on the project's objectives, partners, key accomplishments and resource links established throughout the SoundCoop.

The final SoundCoop Workshop was held in Boulder, CO and online in September 2024. During the two-day workshop, the SoundCoop team shared the culmination of efforts completed by this highly collaborative group and demonstrated how each piece plays an important part in the SoundCoop vision—from software to file formats to visualization. The group also extensively discussed the "collaborative path forward" on which tools, standards and best practices established during the SoundCoop will be or are now being implemented by partners in their large-scale monitoring.

This project enables the Navy to leverage an existing national archive infrastructure, which provides cost savings and efficiencies. Archiving data protects past Navy investments in passive acoustic monitoring and preserves these recordings for ongoing and future analysis of long-term trends and large areas of geographic interest. The project also developed advanced processes for evaluating large-scale open access passive acoustic data. These processes provide standardized interagency methods for analyzing large datasets and make it more efficient to quickly find sounds of interest.

About the Principal Investigator

Carrie Wall is a research scientist at the University of Colorado, Cooperative Institute for Research in Environmental Sciences. She leads the passive acoustic and water column sonar archives at the NOAA National Centers for Environmental Information (NCEI). Dr. Wall holds a Ph.D. from the University of South Florida College of Marine Science.

Key contributors: Leila Hatch (NOAA's Office of National Marine Sanctuaries), Robert Bochenek (Axiom Data Science), Sofie Van Parijs (NOAA's Northeast Fisheries Science Center), Megan McKenna (University of Colorado and NOAA NCEI).

Ongoing and New Start Projects by Investment Area

INVESTMENT AREA 1
DATA TO SUPPORT RISK THRESHOLD CRITERIA

LMR Investment Area 1 improves the Navy's acoustic and explosive impact assessments and validates mitigation requirements. This information is critical to Navy at-sea compliance and permitting, and ultimately helps to ensure uninterrupted training and testing.

Projects in this area can include hearing studies and sound exposure and behavioral response studies. Researchers collect and analyze data pertaining to animal hearing, potential exposure of animals to acoustic and explosive sources and how the animals respond or are affected. These data support risk threshold criteria and inform the Navy's acoustic and explosive impact assessments. Risk threshold criteria are values that estimate the likelihood that certain types of specified effects will occur. These criteria are also used to estimate the distance from sound source to animal response to help determine appropriate measures to reduce impacts to protected marine species. Improving the accuracy of such estimates will reduce overly burdensome mitigation requirements that can reduce training and testing realism.

The following section includes summaries of four ongoing projects and three new start projects.

Ongoing Projects

- Project 32—Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals
- Project 50—Loudness Perception in Killer Whales (*Orcinus orca*): Effects of Temporal and Frequency Summation
- Project 64—3S4–Effect of Continuous Active Sonar and Longer Duration Sonar Exposures
- Project 67—Measuring Behavioral Responses of Goose-beaked Whales to Continuous Active Sonar in the Atlantic

New Start Projects

- Project 69—Effect of Signal Duration on Perceived Loudness in Bottlenose Dolphins and California Sea Lions
- Project 70—Behavioral Observations of Marine Mammals around Impulsive Noise (BOOMIN)
- Project 71—Masking Parameters for Pinnipeds: The Effects of Noise Bandwidth and Level on Signal Detection

MC2 Ian Thomas

Ongoing Projects

Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

Principal Investigators:
Colleen Reichmuth, Jillian Sills
Project Status: Ongoing, Project 32

NEED

N-0103-16: Marine Species Hearing Research Related to the Acoustic Effects Criteria

The Navy needs new data to improve the Navy's acoustic and explosive impact assessments for marine species. Priority interest is in species for which no, or insufficient, data are available. Areas of focus include audiograms of hearing capability in marine species, data on temporary threshold shift (TTS) at multiple frequencies, and effects to fish from the detonation of explosive devices of various charge sizes, depths and distances to the subjects. The Navy needs improved hearing data in order to update risk threshold criteria, reduce the uncertainty of the current impact assessments and validate mitigation measures.

PROJECT

This project addresses the most pressing knowledge gaps concerning auditory biology for Hawaiian monk seals. Achievements thus far include measurements of auditory sensitivity—across the full frequency range of hearing—for a specially trained adult male Hawaiian monk seal, KE18. The resulting data have been used to generate both underwater and in-air audiograms that can be used to support impact assessments of the Hawaiian monk seal's hearing range and sensitivity to sound. This project has also included evaluation of audio and video recordings of KE18's underwater sound production to provide previously unavailable descriptions of underwater calls emitted by male monk seals. To confirm findings at the species level, the project now has been extended to enable similar measurements with a second Hawaiian monk seal.

The work on this project began in 2018 with behavioral testing of KE18's underwater hearing capability and provided an initial description of underwater sound production for the species. During 2019, project efforts were directed to in-air hearing measurements, as well as continuing recordings in water to reveal temporal patterns in sound production. Work during 2020 focused on measuring masked in-air hearing thresholds and completing analysis of the underwater call repertoire. Two comprehensive manuscripts reporting on the work were prepared in 2020 and published in 2021 (see the LMR 2021 Annual Report for citations).

The underwater hearing test results from KE18 revealed that Hawaiian monk seals hear better at lower frequencies than previously believed, although with poorer sensitivity than that of related seal species. Similarly, the in-air hearing test results suggested that monk seals (in the Monachinae subfamily) have low sensitivity to airborne sounds, in contrast to northern seals in the Phocinae subfamily that have exceptional in-air hearing. The audio and video recordings of KE18's underwater sound production enabled the project team to identify and characterize previously unknown call types, and to document the relationship between the monk seal's vocal behavior and reproductive status. Replicating the underwater studies with a second trained seal was recommended as a valuable addition to those results.

KE18 was successfully transported back to Hawaii and Sea Life Park in 2021. The project team contributed to developing information panels that were installed at KE18's new home at the park.

Shortly after KE18's return, another male monk seal, KP2, was transported from the University of Hawaii's Waikiki Aquarium to the University of California Santa Cruz's Long Marine Laboratory. Both seals involved in this project have been

Monk seal KP2.
Colleen Reichmuth, permit 24054

deemed non-releasable by the National Marine Fisheries Service (NMFS) and are housed in long-term human care for zoological display, public education and conservation research.

During 2022, the project team worked with KP2 and trained him to participate in auditory measurements. They measured underwater auditory thresholds across the frequency range of hearing to provide an underwater audiogram. They also maintained an autonomous acoustic recorder within KP2's pool, successfully collecting a full year of underwater recordings with this individual. The recordings will let the team compare the call types and seasonal patterns in vocal behavior with those that were described for KE18.

Steps to prepare for in-air measurements were initiated in 2022, including building a new in-air testing apparatus and training KP2 for the task outdoors. The project also created an educational video for Waikiki Aquarium describing KP2's research in Santa Cruz. The video can be found at: www.waikikiaquarium.org/experience/exhibits/hawaiian-monk-seal-habitat/.

In 2023, the team measured KP2's sensitivity to airborne sounds at six frequencies between 200 Hz and 33 kHz. KP2's hearing—even when evaluated in a semi-controlled outdoor setting—was quite similar to KE18's when tested previously in the quiet conditions of an acoustic chamber. Therefore, this validation effort confirmed that KP2 and KE18 have comparable, species-typical auditory capabilities both in air and in water that can be considered representative for Hawaiian monk seals. A manuscript describing these findings was accepted for publication in late 2024. The team is preparing for KP2's return to the Waikiki Aquarium in coordination with the project partners at Waikiki Aquarium and NMFS.

During 2024, the research focus shifted to the development of a combined detection and classification algorithm for Hawaiian monk seal underwater vocalizations. The team used a YOLO (You Only Look Once) v4 detection network trained on the COCO (Common Objects in Context) dataset to find and classify monk seal vocalizations within generated spectrogram images of acoustic record-

ings. The algorithm was applied to over four years of underwater recordings obtained from KP2 and KE18 in quiet conditions, resulting in a rich dataset of approximately 50,000 calls. These data confirm the species-typical vocal repertoire as well as seasonal and physiological patterns in sound production. Next steps in 2025 include adapting and testing the detector/classifier for field applications with free-ranging Hawaiian monk seals.

The results of this effort will allow the Navy to improve impact assessments and better estimate the potential acoustic effects of Navy training and testing activities.

In 2024, the research team also completed an opportunistic, compact field study to describe the terrestrial calls of Hawaiian monk seals breeding at the remote Kalaupapa National Historical Park on Moloka'i. In cooperation with the National Oceanic and Atmospheric Administration's Hawaiian Monk Seal Research Program at the NMFS Pacific Islands Fisheries Science Center, over 1,000 calls were recorded from several mother-pup pairs and transient mature males. These data will be combined with measurements of hearing sensitivity and masking, as well as ambient noise analyses, to estimate typical communication ranges and potential disturbance zones for Hawaiian monk seals while on shore.

The results of this effort provide a comprehensive understanding of hearing and vocal behavior in endangered Hawaiian monk seals that will allow the Navy to improve impact assessments and better estimate the potential acoustic effects of Navy training and testing activities on Hawaiian monk seals.

About the Principal Investigators

Colleen Reichmuth is an animal behaviorist at the Institute of Marine Sciences, University of California Santa Cruz. She has extensive experience conducting psychological and physiological studies of marine mammals with a focus on sensory biology. Her expertise includes training marine mammals for voluntary participation in research, conducting field studies of animal acoustic communication and promoting best practices for the care and welfare of research animals. Dr. Reichmuth earned her Ph.D. in ocean sciences at the University of California Santa Cruz.

Jillian Sills is a project scientist at the University of California Santa Cruz. She is a skilled bioacoustician who has conducted auditory research with walruses, harbor seals, spotted seals, ringed seals, bearded seals, monk seals, sea lions and sea otters. She also studies sound production patterns in captive and free-ranging pinnipeds and conducts research on the effects of noise on marine mammals. Dr. Sills earned her Ph.D. in biological oceanography at the University of California Santa Cruz.

Key contributors: Graduate students Kirby Parnell (University of California Santa Cruz, University of Hawaii) and Brandi Rusher (University of California Santa Cruz), monk seal specialists Traci Kendall and Beau Richter (University of California Santa Cruz), research fellow Dr. Jeppe Have Rasmussen (University of Copenhagen, University of California Santa Cruz). The National Marine Fisheries Service, Sea Life Park Hawaii and Waikiki Aquarium helped to facilitate this research program.

Loudness Perception in Killer Whales (*Orcinus orca*): Effects of Temporal and Frequency Summation

Principal Investigators:
Alyssa Accomando, Brian Branstetter
Project Status: Ongoing, Project 50

NEED

N-0239-21: Relationship Between Perceived Loudness of a Signal and Signal Length

To understand the potential effects of sounds created by Navy training activities on marine mammals, the Navy needs information not only on physiological effects (i.e., temporary threshold shift, permanent threshold shift), but also how sounds can influence marine mammals' behavioral response. Both context and perceived components of the sound, rather than the physical characteristics alone, may contribute to response. One perceptual component of sound is perceived loudness and one factor that may lower perceived loudness, and therefore reduce the potential for a behavioral response, is the duration of the sound or signal.

PROJECT

This project is investigating perceived loudness in killer whales using a multi-pronged approach:

1. Determine the effect of signal duration on response latency.
2. Determine the effect of signal duration on detection thresholds.
3. Determine the effect of masking noise on duration-dependent detection thresholds.

Originally, the project scope included investigation of subjective loudness of short duration signals compared to long duration signals. However, the animals struggled with the training associated with this task and it became clear that the team needed to move in a different direction. Therefore, the decision was made to focus on the effect of masking noise on duration-dependent detection thresholds instead (number 3 above).

Because current auditory weighting functions are based on pure tone, long-duration signals, and may not generalize to pulsed tones or broadband sounds, the data from this effort may provide modifications for the weighting functions.

The project team is working with three trained killer whales (*Orcinus orca*) with good species representative hearing. Due to their large size and increased sensitivity to lower-frequency sounds, killer whales are currently the best

Killer whales.
Candice Emmons, NOAA

Killer whales.
Robert Schwemmer, NOAA

"hearing surrogates" for other large odontocetes such as beaked whales and sperm whales, where high-quality behavioral audiograms do not exist. Testing is being done at SeaWorld in a quiet and isolated pool that supports an exceptional amount of experimental control over the testing context and acoustic stimuli.

The work is now organized around the following two experiments:

1. **Detection thresholds and response latency as a function of signal duration and frequency**

   The goal is to measure detection thresholds as a function of frequency for different duration signals in additional whale subjects.

2. **Masked duration-dependent detectability of tones**

   This experiment will test how signal detection in noise depends on sound duration. The goal is to provide data indicating how realistic signal and noise levels compare to simple model predictions from auditory weighting functions.

Initial training and data collection efforts were started with two whales in 2021.

In 2022, the project team completed experiment 1 data collection, including additional thresholds measured for 40 and 100 kHz. Other efforts in 2022 prepared for an experiment to evaluate subjective loudness comparison for different duration signals. This phase used a custom software application (Loudness Testing) that controls the experimental stimuli, records the animal's response and logs all variables for analysis. This experiment also required newly constructed and robust testing equipment (in-water equipment used with killer whales needs to be custom-welded by SeaWorld) and animal training for the new experimental protocols. This experiment was discontinued, as previously noted. One manuscript was published in 2022 (see LMR 2022 Annual Report).

New data collection for experiment 1 and the newly defined experiment 2 began in 2023. Other work in 2023 included data analyses, manuscript

preparation and one manuscript publication (see the LMR 2023 Annual Report).

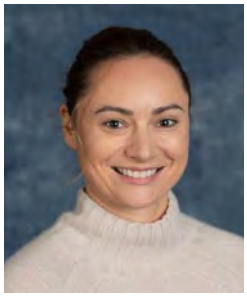
Work in 2024 focused on continued data collection for experiment 2, which is planned for completion in 2025. This study will provide the necessary data to modify current auditory weighting functions to include duration and baseline ambient sound levels as modifying factors. A new manuscript was published in 2024 (see Publication sidebar).

> The data will support the Navy at-sea compliance process and provide improved auditory weighting functions and thresholds needed to develop acoustic criteria.

The data will support the Navy at-sea compliance process and provide improved auditory weighting functions and thresholds needed to develop acoustic criteria. Because the current auditory weighting functions are derived from long-duration pure tones and may not generalize to other types of sounds, developing duration-dependent auditory weighting functions will support perceived loudness estimations for a broad range of signals.

Knowing more about what signals animals can hear, and which signal durations they are most sensitive to, allows the Navy to determine which Navy sound sources need to be analyzed. This improves the Navy's modeling analysis that estimates how many animals may be affected, streamlining the compliance process.

About the Principal Investigators



Alyssa Accomando is a neuroscientist with nine years of experience conducting research at Naval Information Warfare Center Pacific (NIWC Pacific), specializing in animal bioacoustics with environmental and technological applications. Her research includes auditory processing and perception in echolocating animals. Dr. Accomando earned her Ph.D. in neuroscience at Brown University.

Brian Branstetter is a marine natural resources specialist at Naval Facilities Engineering Command Pacific (NAVFAC PAC). He started this project when he was with National Marine Mammal Foundation, before moving to NAVFAC PAC, and is continuing to provide scientific and technical support. Dr. Branstetter's research interests have focused on marine mammal psychoacoustics and cognition, echolocation, auditory masking, whistle production and perception, and vigilance in dolphins. He also has worked on characterizing anthropogenic noise in marine environments. He earned his Ph.D. from the University of Hawaii Manoa.

Publication

Stephens, J., Accomando, A.W., Nease, K., Branstetter, B.K. and Robeck, T.R. (2024). Latencies of conditioned vocal responses to hearing test tones in killer whales (*Orcinus orca*). *Frontiers in Behavioral Neuroscience*, 28. DOI 10.3389/fnbeh.2024.1495579.

3S4—Effect of Continuous Active Sonar and Longer Duration Sonar Exposures

Principal Investigators: Frans-Peter Lam, Petter Kvadsheim, Patrick Miller
Project Status: Ongoing, Project 64

NEED

N-0238-21: Understanding Marine Mammal Hearing and Behavioral Response to Continuous Active Sonar

It has been observed from previous behavioral response studies that signal type and duration of Navy sonar signals may play a role in observed responses in marine mammals. In 2017, LMR began investing in studying and collecting behavioral response data to continuously active sonar as part of the third phase of the Sea Mammals and Sonar Safety (3S3) project (LMR Project 29). However, there is an expanded need to further understand the effects of continuous active sonar on marine mammal hearing and behavioral response, particularly with additional marine mammal species.

PROJECT

The 3S project has been conducting behavioral response studies on six different cetacean species in North Atlantic waters since 2006.

The objectives of phase four of the 3S project (3S4) are to

1. Investigate whether exposure to continuous active sonar (CAS) leads to different types or severity of behavioral responses than exposure to traditional pulsed active sonar (PAS) in killer whales and humpback whales
2. Investigate if responses from short duration experiments predict responses from longer duration exposures conducted over an operationally relevant duration.

The project is supported in partnership with the LMR program and Canadian, French, Norwegian and Dutch naval authorities, research organizations, and the University of Iceland.

The project has completed two of three planned field efforts to collect data on animal responses to short- and long-duration CAS and PAS exposures using real-time GPS location data of multiple tagged subjects. Suction-cup attached mixed-DTAG+ and DTAG3+ units have included a DTAG3 core unit, VHF transmitter and a GPS-Argos unit built by Lotek. The source vessel has been equipped with a goniometer-receiving system for real time reception of Argos transmis-

George Sato, 3S-project


Ellen Hayward, 3S-project

sions, and with the decoding system for GPS location data. For longer term tracking, satellite tags (SPLASH10-F-333B) were deployed early in the trials to collect information on animal movement over a longer timeframe (2–3 month expected tag duration).

During each field effort, the project team works to collect data on animal responses to CAS and PAS, with killer and humpback whales as the target species. These species are found in large numbers on the herring overwintering grounds off northern Norway. Previous behavioral studies have shown that these species avoid the sonar source and cease foraging during exposure. However, humpback whales rapidly resume foraging, while killer whales appear to have more prolonged responses.

The data analyses will include quantitative (state-based modeling of behavior and Mahalanobis distance), and qualitative (severity scoring) analysis of data recorded by the animal-attached tag. The key goals of the data analysis will be to quantify the magnitude/severity of observed behavioral changes during the sonar treatments, compared to the pre-exposure baseline period.

The first field effort, for tagging and CAS exposure, was completed in October 2023. Despite weather and sound source issues, the team concluded this effort with 24 tags deployed (18 mixed-DTAG+ and six LIMPET splash tags) and four controlled exposure experiments (CEEs) (two CAS and two PAS) conducted on multiple animals (19 killer whales and five humpback whales). In addition to the DTAG core unit, a Fastlock GPS logger/ transmitter, and VHS and Argos transmitters, the team included a small video logger on the mixed-DTAG+. The LIMPET splash tags provided GPS and depth-recording. Data collected included behavioral metrics (e.g., dives, vocalizations, GPS position), context (e.g., feeding, prey field mapping), social observations with video and acoustic recordings, oceanographic conditions and sonar signals. Due to technical issues with the sonar source the team had to switch from a 1.3–2.0 kHz hyperbolic frequency modulated signal (transmitted at energy source level of 201 dB re 1 µPa2sm2 during both CAS and PAS) to a 4–6 kHz hyperbolic frequency modulated signal (transmitted at energy source level of 184 dB re 1 µPa2sm2 during both CAS and PAS). Data analyses are underway.

The second field effort was completed in October-November 2024. The team deployed 31 tags, including three Splash tags and 20 mixed-DTAG+ to killer whales and eight mixed-DTAG+ to humpback whales. The team conducted six long-duration, CEEs to 14 animals (ten focal and four non-focal), three with the CAS signal and three with the PAS signal. All six CEEs were on killer whales, during the nighttime feeding context, and using the 1.3–2.0 kHz hyperbolic frequency modulated signal (transmitted at energy source level of 201 dB re 1 µPa2sm2). Data processing and analysis of the combined dataset from 2023 and 2024 is underway.

> This project will provide valuable data to support new assessments.

The project has collected more data than expected to date, but because the team had to use two different sonar frequency bands, and because the whales have a very conspicuous diurnal pattern with intense feeding behavior at night and resting behavior in daytime, more data are needed for conclusive results. The third and final field effort will take place in October 2025.

Products will include published cruise reports, project data reports, peer-reviewed papers and presentations to naval sponsors. End users include the U.S. Navy at-sea compliance community, naval officers of the sponsoring North Atlantic Treaty Organization navies and the scientific community.

Current compliance assessments for Navy sonar are based on traditional PAS technologies. With the higher duty cycle of the new CAS technologies, the Navy needs more information on how multiple species respond to CAS compared to PAS. Furthermore, the longer duration exposures of up to eight hours will provide data that are more relevant to operational scenarios. This project will provide valuable data to support new assessments.

About the Principal Investigators

Frans-Peter Lam, the lead principal investigator, is a senior scientist at The Netherlands Organization for Applied Scientific Research (TNO). Dr. Lam earned his Ph.D. in physics and astronomy from Utrecht University in The Netherlands. His main research interests are the effects of sound on marine mammals and military oceanography.

Co-PIs are Petter Kvadsheim, (FFI (Norwegian Defence Research Establishment)), Patrick Miller, Peter Tyack and Saana Isojunno (University of St Andrews Sea Mammal Research Unit), Charlotte Curé, (CEREMA (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning) France), Paul Wensveen and Filipa Samara (University of Iceland) and Sander von Benda-Beckmann (TNO).

Publications

Kvadsheim, P.H., Miller, P.J.O., Lam, F.P., Wensveen, P.J., Bort, J., Burslem, A., Giovannini, G., Hayward, E., van Ijsselmuide, S.P., Kleivane, L., Reesor, C., van Riet, M.W.G., Roland, R., Siemensma, M. and Sato, G. (2024). Effect of naval sonar exposure on killer whales and humpback whales—3S-2023 cruise report. FFI report 24/00559.

Miller, P. and Samarra, F. (2024). Cruise Report 3S-2023—Iceland Pilot Study Trial. January 2024, available from *pm29@st-andrews.ac.uk*.

Measuring Behavioral Responses of Goose-beaked Whales to Continuous Active Sonar in the Atlantic

Principal Investigator: Douglas Nowacek
Project Status: Ongoing, Project 67

NEED

N-0238-21: Understanding Marine Mammal Hearing and Behavioral Response to Continuous Active Sonar

It has been noted from previous behavioral response studies that signal type and duration of Navy sonar signals may play a role in observed responses in marine mammals. In 2017, LMR began investing in studying and collecting behavioral response data to continuous active sonar (CAS) as part of the third phase of the Sea Mammals and Sonar Safety (3S3) project (LMR Project 29). However, there is an expanded need to further understand the effects of CAS signals on marine mammals, particularly with additional marine mammal species.

PROJECT

This project is designed to test and quantify the behavioral responses of goose-beaked whale (*Ziphius cavirostris*; hereafter *Ziphius*) to Navy mid-frequency active sonar (MFAS) activities that employ CAS signals, using controlled exposure experiments (CEEs) off Cape Hatteras, North Carolina. The location, near but not on a Navy sonar training range, is expected to be populated by animals less habituated to Navy training activities than animals that live on or closer to sonar training ranges. The area also is used for the Navy's Marine Species Monitoring (MSM) program's Atlantic behavioral response study (Atlantic-BRS), which has focused on potential effects of traditional lower duty-cycle signal MFAS activities on *Ziphius* as well as short-finned pilot whales.

The project team will evaluate, on multiple spatial scales, three distinct categories of potential behavioral responses: avoidance, behavioral changes (e.g., interrupted foraging) and changes in social interactions or groupings. Detailed data over both long- and short-term response times will be collected using satellite-linked dive recording tags and multi-sensor high resolution archival tags, respectively. The multi-scale tagging approach mimics the approach successfully used in the Atlantic-BRS to test the responses of *Ziphius* to MFAS activities using traditional lower duty-cycle sonar signals. The team will also use visual and photographic confirmation of the composition of *Ziphius* social groupings. Skin and blubber biopsy samples will be collected, if possible.

The experimental protocols include a pre-exposure period during which baseline behavioral data are collected prior to the CEE, followed by continued monitoring throughout the exposure and post-exposure periods. Experiments will be coordinated with operational Navy surface vessels capable of transmitting CAS signals through well-established procedures developed with U.S. Fleet Forces Command. The project team will deploy a simulated CAS source as a secondary option if CAS-capable Navy vessels are unavailable. Protocols also include full control CEEs (no known CAS or other MFAS exposure) with focal tagged and followed animals where possible, and not to interfere with baseline pre-exposure data collection. All operational parameters, general operating areas and experimental methods are strategically matched to past MFAS CEEs to enable comparisons of any behavioral changes as a function of signal type between conventional lower duty-cycle signals and CAS signals.

Data analyses will use tools developed during the Atlantic-BRS project and within the framework of the Double MOCHA project (mocha.wp.st-andrews.ac.uk), which was co-sponsored by the Office of Naval Research and LMR.

During 2023, the team completed substantial logistical planning efforts and coordinated with a CAS-equipped ship for a CEE. In advance of the planned CEE, the team successfully deployed satellite-transmitting position/dive tags on 11 *Ziphius*. The Navy ship scheduled to participate in the CAS CEE encountered engineering issues enroute and, although the team was unable to complete the CAS CEE, they completed a control CEE (no sonar signal) and successfully collected behavioral data. These data will provide valuable comparison points for future CAS CEE data.

During 2024, the team successfully conducted the first-ever CAS CEE with a U.S. Navy platform, the USS *Thomas Hudner*. The team coordinated closely with U.S. Fleet Forces command in scheduling several CAS-equipped ships for CEE windows, including new approaches with transiting vessels to increase the opportunities for coordination. In advance of the planned CEEs, the team successfully deployed satellite-transmitting position/dive tags on four *Ziphius*, three of which were successfully transmitting data during the CEE. The team relocated tagged and other *Ziphius*, including individuals previously tagged in studies of pulsed active sonar (PAS) throughout the season, which contributed photo-ID data that offer insights on social group compositions and interac-

Goose-beaked whale (*Ziphius cavirostris*) being tagged with a satellite telemetry tag.
Will Cioffi, NMFS permit 22156 (Doug Nowacek/Duke University)

tions. In addition to data collection and analysis, the team published a peer-reviewed paper on the use of ancillary location data in improving received level model estimates for satellite transmitting tags (see the Publication sidebar).

> Results of this effort will support direct comparison between responses to CAS signals and to conventional, lower duty-cycle MFAS signals.

Plans for 2025 include sustained efforts to coordinate with Navy ships to conduct CAS CEEs. Field tagging efforts may include early season survey and location-only tag deployments to evaluate distribution patterns given slightly atypical observations in 2024. Objectives for 2025 include deploying five or more satellite-transmitting and/or high-resolution suction cup DTAGs and conducting up to two CAS CEEs.

Annual reports developed for the Navy Fleet Monitoring Program, which is co-funding this effort, will be submitted following each field effort and during the analytical phase. A final report will be submitted following the analytical phase. The primary products of this study will be empirical measurements of behavioral responses of *Ziphius* to CAS signals within the specified response categories.

Results of this effort will support direct comparison between responses to CAS signals and to conventional, lower duty-cycle MFAS signals. Published results on control behavior, which will be greatly enhanced by the previous years of Atlantic-BRS experiments, and responses to CAS signals will inform Navy at-sea compliance as well as the broader scientific and conservation communities. The results will be directly available for use in the development of future Navy behavioral risk functions. Knowing how animals react to different signal types allows the Navy to better determine which Navy sound sources need to be analyzed. This improves the Navy's modeling analysis that estimates how many animals may be affected, streamlining the at-sea compliance process.

About the Principal Investigator

Douglas Nowacek, Distinguished Professor of Marine Conservation Technology in the Nicholas School of the Environment and the Pratt School of Engineering at Duke University, has been conducting sound exposure experiments since 1993. His work has been with both odontocete and mysticete cetaceans and has included both large scale, multi-vessel and small-scale experiments. He also has consulted widely on assessing behavioral responses of cetaceans to various industrial and naval sound sources. Dr. Nowacek's Ph.D. in biological oceanography is from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution joint program.

Co-PIs are Brandon Southall (Southall Environmental Associates, Inc.) and Andy Read (Duke University's Nicholas School of the Environment).

Publication

Schick, R.S., Cioffi, W.R., Foley, H.J., Joseph, J., Kany, N.A., Margolina, T., Swaim, Z.T., Zeng, L. and Southall, B.L. (2024). Estimating received level in behavioral response studies through the use of ancillary data. *The Journal of the Acoustical Society of America*, 156(6):4169-4180. DOI 10.1121/10.0034617.

New Start Projects

Effect of Signal Duration on Perceived Loudness in Bottlenose Dolphins and California Sea Lions

Principal Investigator: Alyssa Accomando
Project Status: New Start, Project 69

NEED

N-0239-21: Relationship Between Perceived Loudness of a Signal and Signal Length

To understand the potential effects of sounds created by Navy training activities on marine mammals, the Navy needs information not only on physiological effects (i.e., temporary threshold shift, permanent threshold shift), but also how sounds can influence marine mammals' behavioral response. Both context and perceived components of the sound, rather than the physical characteristics alone, may contribute to response. One perceptual component of sound is perceived loudness and one factor that may lower perceived loudness, and therefore reduce the potential for a behavioral response, is the duration of the sound or signal.

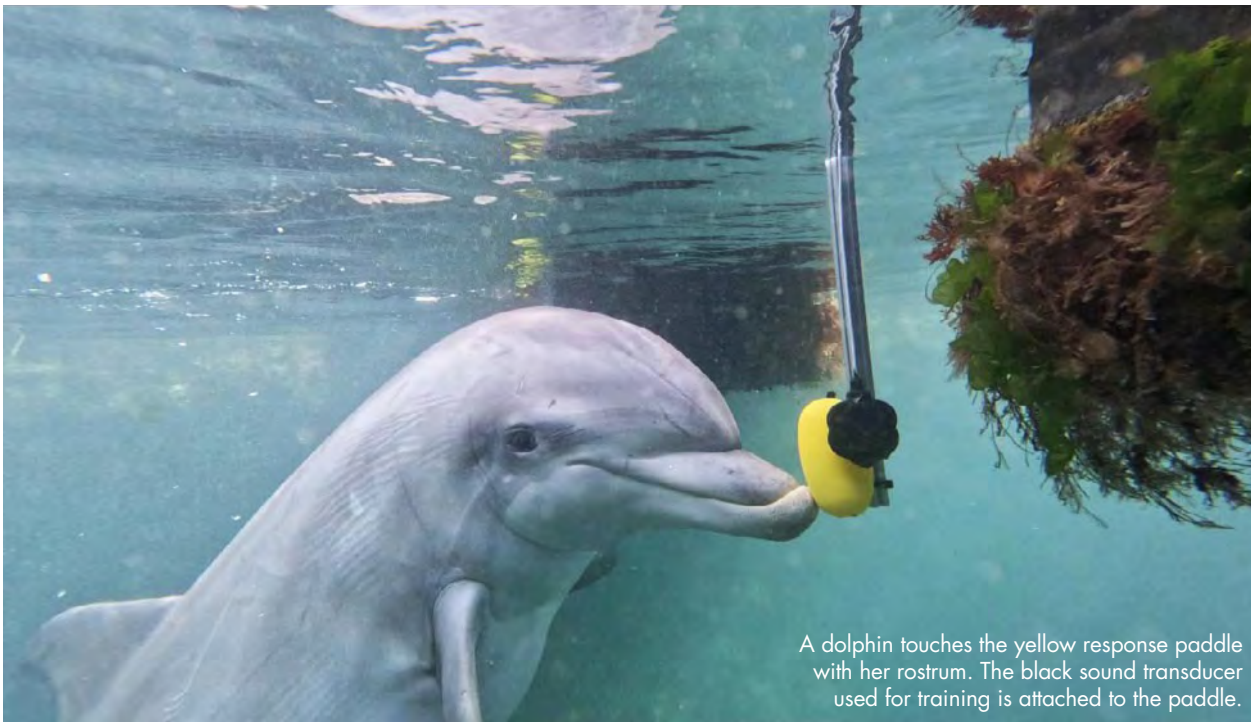
PROJECT

This project is evaluating the perceived loudness of acoustic sources, which might be a better predictor of animal behavioral responses than received level. The duration of each individual sound likely influences how marine mammals perceive how loud the sound is and how they will respond.

The project team is testing both the relationship of hearing sensitivity to sound duration for a wide range of frequencies, and the relationship between perceived loudness and sound duration. The first two tasks in the team's project plan will work with bottlenose dolphins. A possible third task would test California sea lions.

1. **Threshold of signal duration audibility across the hearing range in dolphins**

   This task will use behavioral methods to test two trained bottlenose dolphins (*Tursiops truncatus*). The team will measure the threshold at which signals are audible for frequency-specific stimuli with durations between 25



A dolphin touches the yellow response paddle with her rostrum. The black sound transducer used for training is attached to the paddle.

and 1000 milliseconds (ms). The frequencies used will reflect a sample across the hearing range of dolphins (5, 10, 20, 40 and 80 kHz). Background masking noise will be played during testing to exceed the ambient sound in the testing location, which will elevate hearing thresholds to levels near those of Navy sources (>100 dB). Thresholds will be determined for each combination of frequency and duration for each masking condition.

Navy behavioral response functions are important to evaluating the Navy's impact on marine mammals.

2. **Perceived loudness as a function of signal duration in dolphins**

   This task will also use behavioral methods to test two trained bottlenose dolphins (*Tursiops truncatus*). Perceived loudness will be measured using a loudness comparison test, in which the dolphin indicates which of two sequential tones is louder. The dolphin will indicate which sound (the first or the second) is louder by pressing the corresponding response paddle (i.e., a two-alternative choice task). Responses from multiple trials having different durations and decibel levels will be used to describe the relationship between duration and loudness.

Results from the respective tasks will be used to assess how faithfully the patterns observed in the Task 1 detection threshold data represent actual loudness perception. The project also will provide equal-loudness contours that represent the SPL/duration combinations that create a sensation of equal-loudness magnitude for each test frequency.

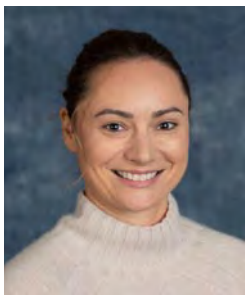
3. **Threshold of signal duration audibility across the hearing range of sea lions (optional)**

   An optional task would collect behavioral detection thresholds from two trained California sea lions (*Zalophus californianus*). Test frequencies will be 1, 2, 4, 8 and 16 kHz, and all other study details will be the same as for dolphins in Task 1.

During 2024, the project team completed Task 1 data collection for dolphins and began training two dolphins for Task 2. During 2025, Task 1 analyses will be completed, dolphin training for Task 2 will continue and Task 2 data collection and analyses will be started.

Navy behavioral response functions are important to evaluating the Navy's impact on marine mammals. The equal-loudness contours could be used to weight these response functions to reflect how perceived loudness changes with source duration. Knowing the signal durations that animals can hear and react to allows the Navy to better determine which Navy sound sources need to be analyzed. This improves the Navy's modeling analysis that estimates how many animals may be affected, streamlining the at-sea compliance process.

About the Principal Investigator



Alyssa Accomando is a neuroscientist with nine years of experience conducting research at NIWC Pacific, specializing in animal bioacoustics with environmental and technological applications. Her research includes auditory processing and perception in echolocating animals. Dr. Accomando earned her Ph.D. in neuroscience at Brown University.

Behavioral Observations of Marine Mammals around Impulsive Noise (BOOMIN)

Principal Investigators:
Erin Falcone, Stephanie Watwood
Project Status: New Start, Project 70

NEED

N-0281-23: Research that Pertains to the LMR Program Investment Area *Data to Support Risk Threshold Criteria*

The U.S. Navy uses the Navy Acoustic Effects Model (NAEMO) for modeling the sound field around Navy training and testing events, which can include detonations that generate explosive sound, to assess their impact on marine species. The effects of explosive sounds on marine mammals are poorly known. More data are required to understand how cetaceans respond to explosive sounds in the open ocean.

PROJECT

This project is working to describe the behavioral response of cetaceans to anthropogenic impulsive noise sources and to verify the explosive propagation modeling for NAEMO. An LMR-funded controlled explosive exposure experiment (Project 35) collected data that can be used to verify propagation modeling of explosive events in NAEMO. Prior to the Project 35 detonations, six Sound and Motion Recording and Transmitting (SMRT) tags were deployed (five on animals, one floating in the area) to collect on-animal sound measurements with concurrent behavioral data. Data from additional SMRT tags deployed on the Southern California Anti-Submarine Warfare Range (SOAR) during other Navy-funded projects will also be evaluated for opportunistic impulsive sound exposures in coordination with data from SOAR hydrophones and Marine Mammal Monitoring on Navy Ranges (M3R) data collected from SOAR.

The project includes three tasks:

1. **Before/During/After assessment of behavior during controlled detonations**

   The team will evaluate vocalization data from SOAR hydrophones and behavioral data from the five SMRT tags deployed on animals prior to the July 2023 controlled explosive exposure experiment (LMR Project 35).

2. **Comprehensive assessment of cetacean response to impulsive sounds**

   The team will evaluate data from previously deployed SMRT tags to examine responses to opportunistic impulsive event exposures.

3. **NAEMO validation**

   Team members from the Naval Undersea Warfare Center Newport (NUWC) will conduct a validation study of the NAEMO model using data collected from the July 2023 controlled explosive exposure experiment (LMR Project 35).

Through these tasks, the project will assess if

- Whales exposed to impulsive sounds respond by altering their behavior (e.g., diving, horizontal movements, vocalizations)

SMRT tag on a goose-beaked whale.
Greg Schorr, permit 21163 (MarEcoTel)

- Responses to impulsive sounds are mediated by exposure characteristics (e.g., sound exposure levels (SEL), sound pressure levels (SPL), distance to source, duration, frequency of use)
- Received levels recorded on the tag are correlated both with received levels (RL) modeled using source characteristics and location, and with RLs recorded on SOAR hydrophones
- Received level metrics from modeled data differ appreciably from measurements for the equivalent weights of explosives modeled.

> Understanding the behavioral response of marine mammals to impulsive sounds is important to the Navy's monitoring and mitigation efforts.

Analyses of data from the Project 35 controlled explosive experiments began in mid-2024 and will be completed by early 2025. Task 1 preliminary findings include fine-scale changes in diving by a tagged beaked whale, which were coincident with the three highest SPL signals from the controlled detonations. Task 3 preliminary findings show that modeled SPL and SEL values from NAEMO were consistently higher than measured values collected under Project 35. Completion of propagation model verification is expected by the end of 2026. Task 2 analyses of previously collected SMRT data will begin in 2025 and continue into 2026. This work will leverage model development for assessing response to sonar to assess responses to impulsive sounds in a much larger sample of data than the controlled detonations.

Data and analyses will be distributed in technical reports and peer-reviewed publications. The technical report on explosive propagation model verification will be incorporated by reference into Navy compliance documentation.

Understanding the behavioral response of marine mammals to impulsive sounds (particularly explosives) is important to the Navy's monitoring and mitigation efforts. This project will provide both detailed behavioral data and accurate sound metrics (e.g., SEL, SPL) made possible by using high-resolution, multi-sensor tag data from multiple cetacean species around Navy explosive testing. In addition to improved behavioral response assessments, verifying the NAEMO explosive propagation model will help inform future acoustic impact modeling assessments and improve accuracy and reliability of modeling data.

About the Principal Investigators

Erin Falcone, a research biologist at the Foundation for Marine Ecology & Telemetry Research, is a cetacean photo-ID and tagging specialist. She has been a principal investigator of marine mammal studies at the Southern California Offshore Range since 2006.

Stephanie Watwood has extensive experience in collecting and analyzing cetacean acoustic data, particularly related to cetacean behavior. She has been working at the Naval Undersea Warfare Center studying the impact of anthropogenic activities on marine species since 2009. Prior to that, she completed a Ph.D. and post-doctoral post at Woods Hole Oceanographic Institution, where her research focused on social and vocal behavior of a variety of mammalian species.

Masking Parameters for Pinnipeds: The Effects of Noise Bandwidth and Level on Signal Detection

Principal Investigators:
Colleen Reichmuth, Jillian Sills
Project Status: New Start, Project 71

NEED

N-0281-23: Research that Pertains to the LMR Program Investment Area *Data to Support Risk Threshold Criteria*

The Navy is interested in research regarding potential impacts to marine species from Navy training and testing activities, primarily focused on potential impacts from sound (e.g., hearing studies, sound exposure and behavioral response studies).

PROJECT

This project is focused on providing quantitative auditory masking data for pinnipeds (odobenid, otariid and phocid carnivores) to improve knowledge of hearing and masking in these taxa and support at-sea compliance efforts within the Navy. The project expands upon another LMR-funded effort (LMR Project 61: Auditory Masking in Odobenid and Otariid Carnivores) that characterized auditory masking from simultaneous noise in an odobenid carnivore, the Pacific walrus (*Odobenus rosmarus divergens*), and an otariid carnivore, the California sea lion (*Zalophus californianus*). With the addition of a phocid carnivore, this study includes one representative species from each of the three pinniped families. Results will describe auditory masking as a function of noise bandwidth and level, improving efforts to understand and predict the effects of noise on free-ranging marine mammals.

The team is conducting behavioral audiometric testing with trained animals to estimate critical bandwidths. Controlled noise fields are established in outdoor conditions to enable the measurement of masked hearing thresholds. Testing uses one-second tonal signals at target frequencies between 0.1 and 16 kHz and measures masked hearing thresholds for these signals in the presence of spectrally flattened, spatially even white noise of varying bandwidths. Results will be used to determine critical bandwidths for each species at each test frequency. These critical bandwidths describe the specific frequency range of noise that contributes to masking a given sound.

For the otariid and phocid study subjects, additional audiometric testing in the controlled acoustic conditions of a hemi-anechoic acoustic chamber will support investigating the effect of noise level on the amount of masking. The results will help to determine masking onset and growth at each test frequency (i.e., determine associated noise levels resulting in no masking, partial masking and full masking). Data will be evaluated to determine: 1) at what point surrounding noise begins to influence hearing, 2) how the amount of masking changes with increasing noise level, 3) at what noise level critical masking ratios begin to apply and 4) whether these masking patterns vary across frequency or species. Information from

California sea lion at UCSC's Long Marine Laboratory.
C. Reichmuth, NMFS permit 23554

both phases of this study can ultimately be applied to improve predictive masking models and to inform our understanding of auditory biology in marine mammals.

The auditory data resulting from this work will improve impact assessments of potential acoustic effects resulting from Navy training and testing activities.

The team completed collecting critical bandwidth data for the walrus, sea lion and bearded seal during 2024. Absolute critical bandwidths (in Hz) increased reliably with increasing frequency. At higher and mid-range frequencies (4000–16000 Hz), critical bands were similar for each subject. However, at lower frequencies (500 Hz and below), the seal's critical bands were substantially narrower than those estimated for the sea lion and walrus. This indicates that seals have relatively enhanced frequency resolution at low frequencies. These data can be used directly to improve masking models for pinnipeds. In 2024 the sea lion was also trained for data collection in the acoustic chamber, and masking onset data were subsequently collected between 0.5 and 16 kHz. In preparation for additional data collection during 2025, two spotted seals with excellent low-frequency hearing were introduced to the study facility. Data collection with these seals will include both critical bandwidth and masking onset measurements, which will increase sample sizes and strengthen the conclusions of this study. Data analysis and writing are also planned for 2025. Manuscripts from the project are expected in 2025 and 2026.

The auditory data resulting from this work will improve impact assessments of potential acoustic effects resulting from Navy training and testing activities in regions that include overlapping habitats for odobenid, otariid and phocid carnivores. This research will improve risk threshold criteria by filling several data gaps related to auditory masking and providing information on marine mammal hearing.

About the Principal Investigators

Colleen Reichmuth is an animal behaviorist at the Institute of Marine Sciences, University of California Santa Cruz. She has extensive experience conducting psychological and physiological studies of marine mammals with a focus on sensory biology. Her expertise includes training marine mammals for voluntary participation in research, conducting field studies of animal acoustic communication, and promoting best practices for the care and welfare of research animals. Dr. Reichmuth earned her Ph.D. in ocean sciences at the University of California Santa Cruz.

Jillian Sills is a project scientist at the University of California Santa Cruz. She is a skilled bioacoustician who has conducted auditory research with walruses, a variety of seals (including harbor, spotted, ringed, bearded and monk seals), sea lions and sea otters. She also studies sound production patterns in captive and free-ranging pinnipeds and conducts research on the effects of noise on marine mammals. Dr. Sills earned her Ph.D. in biological oceanography at the University of California Santa Cruz.

Key contributors: Ryan Jones (UC Santa Cruz), Ann Bowles (SeaWorld San Diego).

INVESTMENT AREA 2
DATA PROCESSING AND ANALYSIS TOOLS

LMR Investment Area 2 projects develop tools to enable more efficient data processing and improve analysis methods. These tools provide more technologically advanced and cost-effective solutions to improve the Navy's capability to utilize data and information to maintain the Navy's competitive advantage in the undersea domain. The ability to collect, process, exploit and disseminate vast amounts of information is key to continually advancing the Navy's undersea capabilities.

This investment area also aligns with the Navy's strategy to increase the use of machine computing tools to optimize data and analytics. Developing tools to automate the processing of large amounts of data can reduce costs, increase productivity and provide consistency. Research on data analysis tools can improve existing methods or foster development of new methods, both of which provide improved data products and results. Projects in this area can include new detection and classification algorithms, improvements to software programs or development of novel analytical methods.

The following section includes summaries of four ongoing projects. There were no new projects started in 2024.

Ongoing Projects

- Project 49—Combining Global OBS and CTBTO Recordings to Estimate Abundance and Density of Fin and Blue Whales
- Project 60—Historic ARP and HARP Passive Acoustic Recording Archiving with NCEI
- Project 62—Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses
- Project 63—Cetacean Caller-ID [CETACID]: Validating Approaches for Identifying Focal Communication Signals Using Acoustic Recording Tags

MC1 Greg Johnson

Ongoing Projects

Combining Global OBS and CTBTO Recordings to Estimate Abundance and Density of Fin and Blue Whales

Principal Investigator: Danielle Harris
Project Status: Ongoing, Project 49

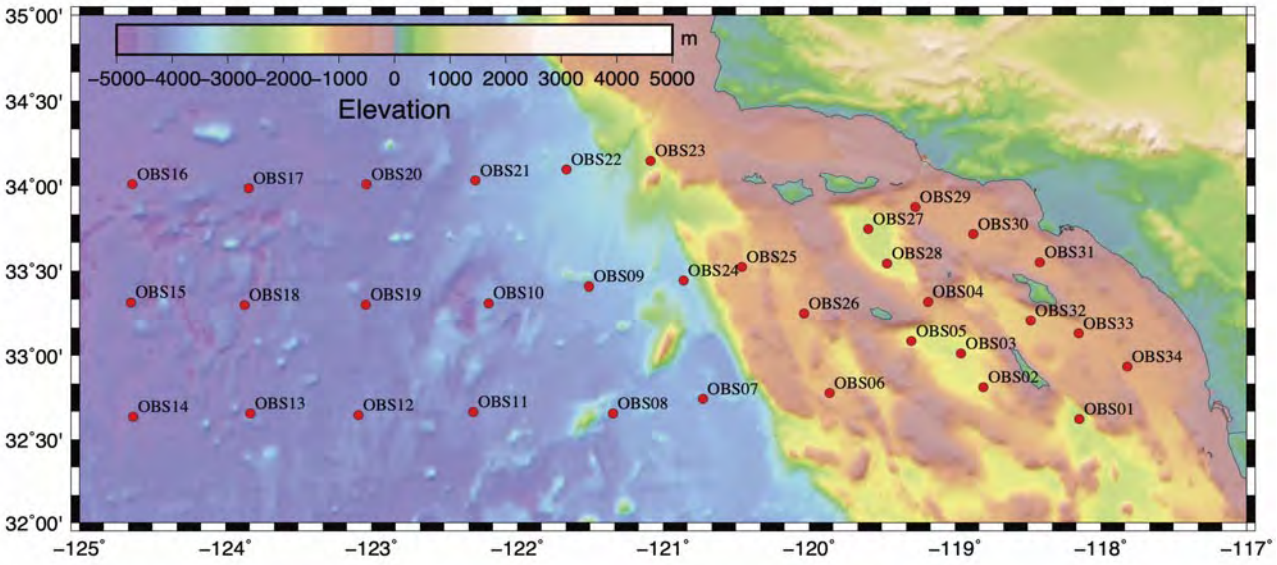
NEED

N-0206-19: Demonstration and Validation of Passive Acoustic Monitoring Sparse Arrays to Estimate the Density of Low-frequency Whales Over Large Spatial Areas

Marine mammal density estimates are a critical input for the Navy's acoustic effects modeling using the Navy acoustic effect model (NAEMO). Although the ship and aerial visual surveys traditionally used to estimate marine mammal density are viable for the Navy, such surveys are limited in spatial and temporal coverage. The Office of Naval Research Marine Mammals and Biology (ONR MMB) program has developed passive acoustic monitoring (PAM) approaches using sparse arrays in which sensors may be distributed evenly but widely over a large area of interest. These are often referred to as 'platforms of opportunity' when their primary monitoring purpose is not for marine mammals. Examples include Ocean Bottom Seismometers (OBS) and Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System (CTBTO IMS) recorders. Density estimation methods have been applied to a few case studies using both OBS and CTBTO IMS data containing fin and blue whale calls. While these studies have demonstrated the utility of OBS and CTBTO IMS data, the techniques to estimate range to calling animals and to estimate density still need to be compared and validated under different conditions to be able to fully utilize the worldwide datasets.

PROJECT

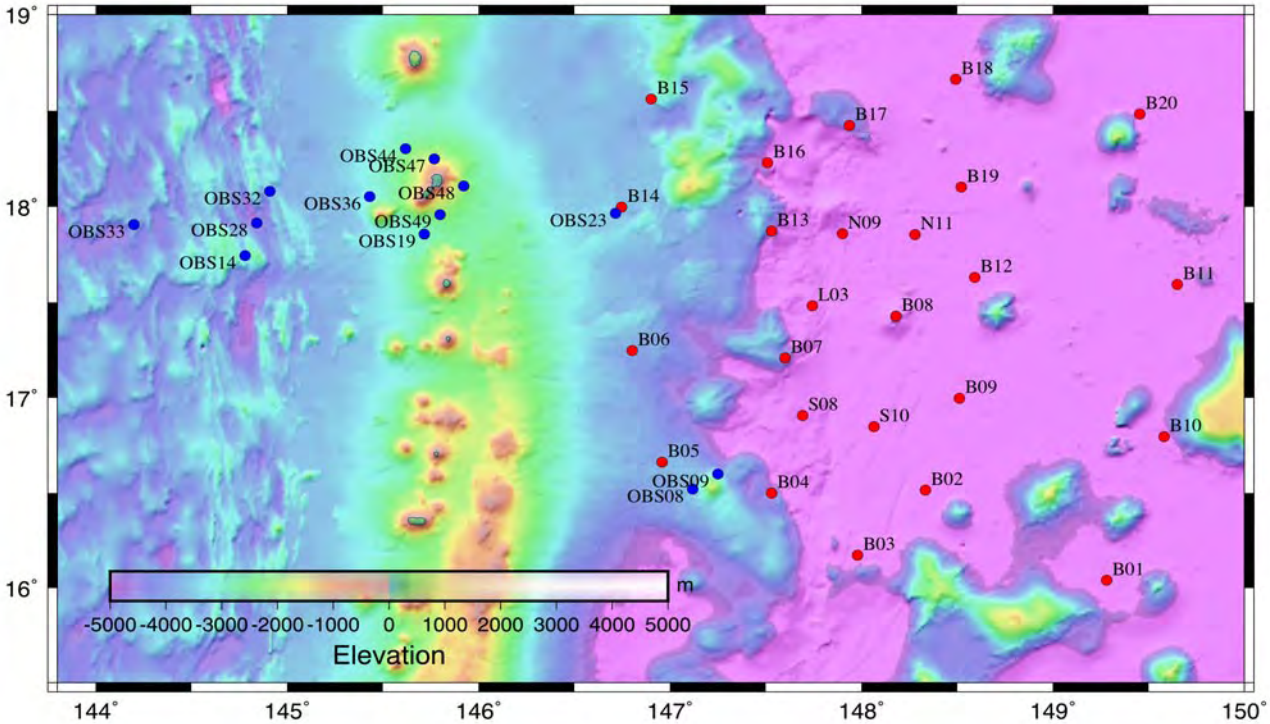
This project is working to demonstrate and refine a suite of methods previously developed to obtain density estimates across a variety of OBS and CTBTO IMS deployments. The data used will reflect a variety of instrument configurations and acoustic propagation conditions. The suite of density estimation methods demonstrated for both OBS and CTBTO IMS data will provide the framework for a set of software tools and training materials to enable a wide range of stakeholders to estimate blue and fin whale density from OBS and CTBTO IMS data and other similar instrumentation.



Map showing an example of an Ocean Bottom Seismometer array deployed for the Albacore seismic experiment off the coast of Southern California, August 2010–September 2011.

This work is co-funded by LMR and ONR MMB and will build on information compiled under previous ONR MMB funding. The early tasks, funded by ONR MMB, have included reviewing existing OBS and CTBTO IMS datasets from around the world, selecting a set of case study datasets containing blue whale and/or fin whale calls, comparing ranging methods, evaluating results and developing methods for density estimation. Varying conditions such as spatial configuration, hardware specifications and oceanographic settings of different arrays will dictate which signal processing methods, and therefore density estimation methods, can be applied to a given dataset. The first part of the LMR-funded portion of the project is focused on signal processing of the OBS and CTBTO IMS case study datasets and implementing the density estimation methods developed under ONR funding. An additional task under this phase will include analyzing the case study datasets to explore various ecological and behavioral questions at a range of scales, from analyzing fine-scale tracks of calling whales to assessing large-scale spatial and temporal patterns of animal vocal activity. The project team will then focus on documenting the research software and case study datasets and developing training materials. The team will configure the software developed during the project so that the different code modules and data formats work together. This includes ensuring that the code for each ranging method produces outputs that are formatted for use with the density estimation algorithms (typically written in R, a free statistical software package).

Training materials will combine the various algorithms and will include developing a flowchart to help users in different geographic areas produce density estimates from their OBS or CTBTO-IMS instruments. These training materials will contain extensive documentation and examples. This will provide the basis for future work to incorporate these techniques into a single user-friendly package.



Two OBS deployments in the Marianas region from June 2003–May 2004 (blue) and February 2012–February 2013 (red). Instrument sample rate: 128 Hz (blue) 100 Hz (red). Instrument spacing: 15+ km (blue), ~30–100 km (red). Data from OBS B19 are being used in the project.

Fin whale.
Jeff Foster, NMFS permit 16111

The project began with the ONR MMB-funded tasks of comparing ranging methods and developing methods for density estimation. Work in 2023 continued those tasks but also focused on LMR-funded tasks of (1) preparing both OBS and CTBTO-IMS datasets for the density estimation tasks in 2024 and (2) organizing software and documentation and developing training materials.

The techniques being demonstrated through this project will potentially make available extensive datasets reflecting large geographic areas at relatively low cost.

Work in 2024 focused on preparing publications from the completed ONR MMB-funded tasks and continuing LMR-funded tasks. The team estimated blue or fin whale densities in seven identified case studies across three different oceans and continued organizing the software documentation and training materials. Further, a Ph.D. student, who will work on a large-scale OBS deployment in the Atlantic Ocean to investigate fin whale density and distribution, started in 2024. Work in 2025 will see the completion of the case studies and training materials. All material will be accessible via the project's website (under development).

The techniques being demonstrated through this project will potentially make available extensive datasets reflecting large geographic areas at relatively low cost. This work will facilitate the use of both OBS and CTBTO-IMS data by synthesizing and refining existing ranging and density estimation methods for these platforms, as well as creating guidance documents and tools for the Navy and other stakeholders to use.

About the Principal Investigator

Danielle Harris is a Senior Research Fellow at the Centre for Research into Ecological and Environmental Modelling at the University of St Andrews, where she earned her Ph.D. in biology and statistics. Dr. Harris' research focuses on using acoustic data to monitor wildlife populations, in particular developing methods to estimate the density and abundance of marine mammal species.

Co-PIs are Len Thomas, Tiago Marques and Peter Tyack (University of St Andrews, UK), Kevin Heaney (Applied Ocean Sciences, LLC, VA, USA), Luis Matias (University of Lisbon, Portugal), David K. Mellinger (Oregon State University, OR, USA).

Historic ARP and HARP Passive Acoustic Recording Archiving with National Centers for Environmental Information (NCEI)

Principal Investigator: Kaitlin Frasier
Project Status: Ongoing, Project 60

NEED

N-0260-22: Research that Pertains to the LMR Program Investment Area *Data Processing and Analysis Tools*

The Navy is interested in developing methods to improve the efficiency of processing and analyzing marine species data and providing cost effective solutions to enhance marine species monitoring capabilities (e.g., detection and classification algorithms, passive acoustic monitoring automated processing tools, statistical methods).

PROJECT

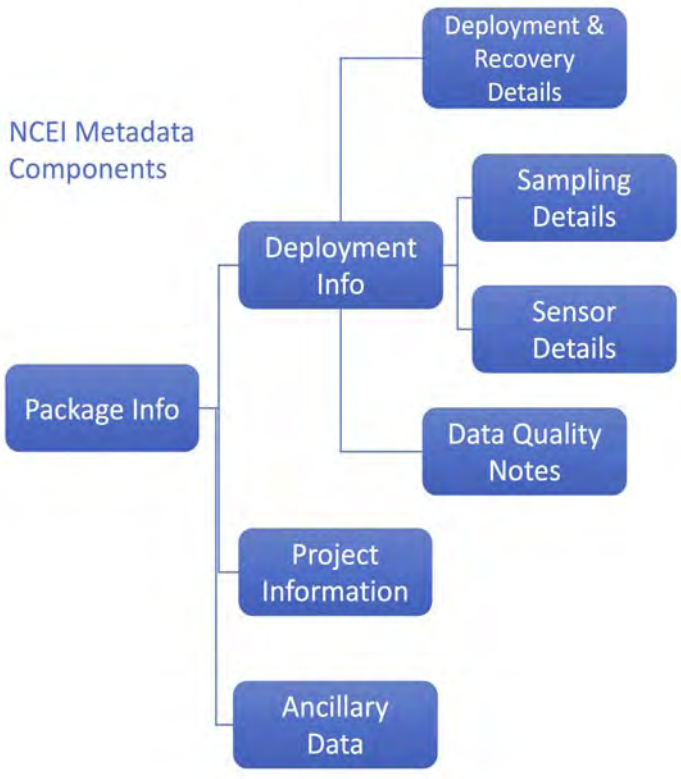
With prior Navy funding, the Scripps Whale Acoustic Laboratory has collected an extensive set of passive acoustic data using Acoustic Recording Packages (ARPs) and High Frequency Acoustic Recording Packages (HARPs). These data are at risk of deteriorating or being lost without proper means of archiving the data. This project is focused on preserving the oldest sets of data, collected between 1999 and 2009. Archiving these datasets includes consolidating the datasets, ensuring metadata integrity and physically transferring these datasets to National Centers for Environmental Information (NCEI), which has been working to preserve passive acoustic monitoring data and make them publicly accessible for future analysis. The project team is collaborating with Navy entities and NCEI staff to develop and streamline archiving processes to improve the feasibility of future archiving efforts.

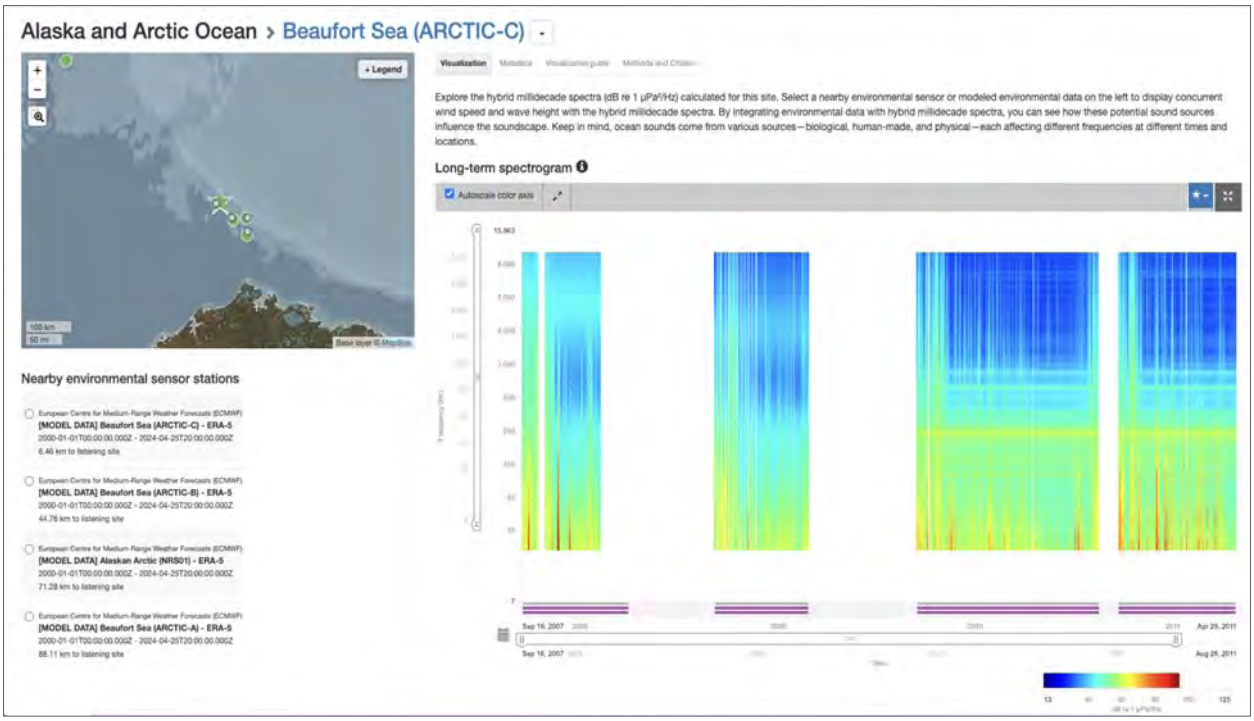
The project is focused on two core tasks: archiving data and participating in a case study project that is part of the Sound Cooperative (SoundCoop), also called the Passive Acoustic Monitoring National Cyberinfrastructure Center. (For information on a related project, see LMR Project 66 on page 60.)

1. **Archiving Data**

   Prior to archiving passive acoustic data at NCEI, the Navy determined which datasets needed pre-archival security screening at the Navy's Commander Undersea Surveillance. It was determined that a portion of the dataset did not need to be screened, and the team could move forward with setting up a process to archive this data.

   In 2023, in coordination with NCEI software developers, a programmatic workflow tool "PassivePacker" was developed to automate the process of compressing and packaging acoustic datasets for the NCEI archive. Three test packages not requiring security screening were packaged using this tool and shipped to





Soundscape metrics data from early HARP recordings ingested by NCEI and displayed on SoundCoop data portal.

NCEI, where they are now publicly discoverable online. Once the test packages were successfully archived, the team used the established process to package and submit to NCEI the remaining data that did not require screening. This included sonobuoy data collected during 2007–2023 CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruises and a portion of the HARP data (approximately 20 percent).

Also, during 2023, the project team aggregated and sent 140 terabytes of uncompressed HARP recordings, comprising approximately 129 individual deployment datasets, to the Navy's Commander Undersea Surveillance for pre-archival security screening. In addition, a set of 23 ARP recordings were reprocessed and sent for security screening.

Data sent for security screening were returned in the second half of 2024. In addition, a new batch processing tool, Passive Acoustic Collection Engine (PACE), was designed and implemented by NCEI for use in packaging multi-deployment passive acoustic submissions. In 2025, the team will use the PACE tool to process and package all remaining data for submittal to NCEI for archiving.

2. **SoundCoop Case Study Project**

The team provided data for the case study "*Showcasing Utility of Centralized Archive for Priority Federally Funded Datasets*." Datasets recorded in Beaufort and Arctic waters between 2004 and 2009 were identified in coordination with NCEI as inputs for the case study project.

In 2023, the team computed soundscape metrics for these datasets using the software package Manta. These were packaged using NCEI's PassivePacker. Project members participated in a series of virtual project meetings and an in-person project meeting at NCEI to provide insight on the feasibility of product generation and how these products could be used for interdisciplinary research. The project lead also

Map showing historic HARP data ingested to date at NCEI.

helped an NCEI contractor to apply existing machine learning algorithms to these products for data classification.

The SoundCoop case study concluded in 2024. During 2024, the project lead participated in end user meetings and contributed to preparing a case study manuscript.

> Archiving these datasets protects past Navy investments in passive acoustic monitoring.

Archiving these datasets protects past Navy investments in passive acoustic monitoring and preserves these time series and early recordings.

Including the data in the NCEI archive will enable the data to be used in aggregate to help to quantify long-term changes in marine soundscapes. The effort has also helped to evaluate and advance processes for large-scale open access passive acoustic data archiving and hosting at a national level.

About the Principal Investigator

Kaitlin Frasier, Assistant Researcher with the Scripps Machine Listening Laboratory, has 15 years of experience working with HARP data and specializes in the use of multi-terabyte passive acoustic datasets for marine mammal monitoring. She has initiated an archiving effort in coordination with NOAA Southeast Fisheries Science Center for passive acoustic data collected in their region, and has also assisted with preparing, documenting and archiving acoustic challenge datasets related to the biennial Detection, Classification, Localization and Density Estimation (DCLDE) workshop. Dr. Frasier earned her Ph.D. in biological oceanography at Scripps Institution of Oceanography, University of California San Diego.

Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses

Principal Investigator: Peter Dugan
Project Status: Ongoing, Project 62

NEED

N-0260-22: Research that Pertains to the LMR Program Investment Area *Data Processing and Analysis Tools*

The Navy is interested in developing methods to improve the efficiency of processing and analyzing marine species data and providing cost effective solutions to enhance marine species monitoring capabilities (e.g., detection and classification algorithms, Passive Acoustic Monitoring automated processing tools, statistical methods).

PROJECT

This project is enhancing the shared software package, Raven-X, which was principally designed as a common acoustic processing software package to handle big data. Originally developed through funding from the Office of Naval Research, and through coordination with Cornell University and Marine Acoustics Inc., Raven-X successfully demonstrated the ability to analyze large, complex, ocean-scale acoustic datasets.

The Raven-X development team includes members from Naval Undersea Warfare Center (NUWC) and the Naval Information Warfare Center (NIWC) Pacific. The team plans to integrate existing acoustic detection, classification and location (DCL) algorithms into Raven-X. Both NUWC and NIWC have DCL algorithms that are customized for their needs and data formats.

As an initial case study, the team set out to demonstrate the benefits of the Raven-X software package by incorporating an improved sonar detector that was developed under a now completed LMR project, Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar (Project 34; see LMR 2022 Annual Report for final summary). The Raven-X team then enhanced the detector by developing an advanced software package that uses intelligent machine learning methods to identify active sonar in large collections of acoustic recordings. By using the Raven-X software package, and Cornell's distributed computers, the team was able to successfully scan for sonar within seven years of acoustic recordings from the joint Navy and NOAA project, SanctSound.

During 2023, the team successfully deployed and shared the Raven-X software package to labs both

Humpback whales.
J. Moore, NOAA

within and outside Navy, including NOAA's National Center for Environment Information (NCEI). The team was able to utilize the tools within Raven-X to convert nearly two decades of community-provided ocean recordings into calibrated sound measurements. This work has allowed the community, largely led by the SoundCoop team (see Project 66, page 60), to develop recommended standards for ambient sound measurements. These recommended standards were directly integrated into the Raven-X software package to support future analysis.

> The teams will be able to holistically analyze the large quantities of U.S. Navy archival data which have been collected on a variety of ranges over several decades.

Also in 2023, the team demonstrated the ability to integrate NUWC and NIWC algorithm technologies into Raven-X. NIWC's software package (Generalized Power Law) and NUWC's archive spectrogram recordings were integrated into Raven-X, and the team was able to obtain high-resolution tracking locations for low-frequency baleen whales.

In 2024 the project focused on integrating the Raven-X technologies into the NUWC/NIWC computing systems. Taking advantage of strategic Navy software investments, the tools will be integrated into NUWC's M3R (Marine Mammal Monitoring on Ranges) computing cluster, as well as into NIWC's WARP (Whale Acoustics Reconnaissance Project) analysis lab. The project continued to develop computer code to integrate existing DCL algorithms into Raven-X. As an additional case study, the team worked on using Raven-X to process seven years of data from the Pacific Missile Range Facility hydrophone array to obtain fin whale calling data.

In 2025 the project will process a series of large datasets recorded from the Southern California Training Range. The team will focus on using Raven-X to read three types of Navy data formats: DAT, packet and archive. New and existing machine learning methods in Raven-X will be used to classify several call types from baleen whales. These methods will be applied across three years of archival recordings, from 2017 to 2019, producing an estimate of animal presence/absence. At least two different locator packages will be added to Raven-X. Each package will be extended to work across all three Navy formats.

When this project is completed, NIWC and NUWC will be able to apply detection, classification and localization algorithms across multiple recording formats, to both historic and current range data. The teams will be able to holistically analyze large quantities of U.S. Navy archival data that have been collected on a variety of ranges over several decades and have the capability to study how different algorithms work across different various data formats and ocean scenarios.

About the Principal Investigator

Peter Dugan is the Raven-X lead at the Naval Undersea Warfare Center in Newport, R.I. Dr. Dugan has high-level engineering experience focused on applied analytical software development systems science. He earned his Electrical Engineering and Computer Engineering Ph.D. from Binghamton University.

Cetacean Caller-ID [CETACID]: Validating Approaches for Identifying Focal Communication Signals Using Acoustic Recording Tags

Principal Investigator: Frants Jensen
Project Status: Ongoing, Project 63

NEED

N-0259-22: Improve the Ability to Identify Calling Individual from Acoustic Tags

The Office of Naval Research (ONR) Marine Mammals and Biology program has previously developed marine mammal tag technology to collect marine mammal movement, diving and acoustic data. Acoustic data from these tags have been useful for detecting sounds received, as well as the sounds produced, by the tagged animal or surrounding animals of conspecifics (i.e., same species). Data specifically from the tagged animals are useful for evaluating baseline behaviors, response and calling or cue rates that may be used in other applications such as estimating detectability or passive acoustic based density estimation methods. Previous approaches have demonstrated the ability of using other sensors on the tags, such as the accelerometer, to link recorded calls to the tagged individual. However, there has not been focused effort on further developing approaches to associate detected calls to the tagged individual. The Navy needs demonstrated approaches and tools for using existing tag sensors to identify which calls detected are associated with the tagged individual.

PROJECT

This project is testing a suite of methods to identify focal signals of both baleen and toothed whales in tag data. Unique datasets in which entire groups of animals have been instrumented with acoustic tags that use relatively high accelerometer sample rates (e.g., DTAG3, DTAG4 and newer Acousonde tags) are being used to validate methods. This will provide ground truth data where calls from tagged animals are recorded on both the source animal tag and simultaneously with tags on other nearby conspecifics.

The project team started the project by investigating and refining approaches for call identification in low-frequency baleen whale species and mid-frequency toothed whales. Using results from that

Instrumenting a humpback whale with a DTAG4 sound and movement recording tag in Stellwagen Bank National Marine Sanctuary.
NMFS permit 27272 (Dave Wiley)

effort, the team is working to demonstrate and validate call identification techniques.

Analytical methods for baleen whale call identification being investigated include:

- **Accelerometer vibration intensity**
  Implement existing methods using an accelerometer signal and evaluate multiple approaches to define decision criteria for differentiating focal signals.
- **Sound-to-vibration energy ratio**
  Multiple conditions can affect call detection from accelerometer data, either inflating call rates or missing detections. The team will use this energy ratio to analyze data.
- **Vector sensor localization**
  The team will adapt well-established vector sensor processing techniques, such as those used to localize sounds in directional frequency analysis recorder (DIFAR) sonobuoys, to estimate sound direction and identify focal sounds with a consistent direction-of-arrival.

Methods for the mid-frequency species include:

- **Received level and angle-of-arrival information**
  Researchers will incorporate improved Time Difference of Arrival algorithms into analysis tools for digital acoustic recording tags (DTAG) and use simulations and empirical data to assess how call frequency and bandwidth affect angle-of-arrival estimation.
- **Spectral distortion**
  The team will measure the ratio of fundamental to harmonic energy within calls from prior analyses of dolphin whistles for focal identification.
- **Low-frequency vibrations associated with sound production**
  This will use high sample-rate accelerometers to try to pick up low-frequency vibrations associated with sound production, similar to the accelerometer vibration work for baleen whales.

To validate techniques for caller identification the team will use datasets in which all animals within a social group are simultaneously tagged with

Bottlenose dolphins.
Gary Barone, NOAA

Humpback whales surfacing in Stellwagen Bank National Marine Sanctuary.
Mason Weinrich, NMFS permit 27272 (Dave Wiley)

acoustic recording tags. For baleen whales, they are collecting data on humpback whales in Stellwagen Bank National Marine Sanctuary and will also leverage the dataset from LMR Project 44 (Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales) that focused on southern right whales in Brazil. For toothed whales the team is collecting data on bottlenose dolphins in Sarasota Bay, Florida, and leveraging datasets from an ONR project on small groups of pilot whales in the Strait of Gibraltar (Spain).

An additional effort to integrate tag data and methods into PAMGuard will be considered depending on the results of the previous effort.

The primary tasks of methods investigation, demonstration and validation will be completed within the first three years of the project, with an estimated completion in 2026. During 2023 the team created a database of baleen whale calls with synchronized audio and accelerometer data that will be important for understanding limits of caller-ID methods across species. The team also completed the first field effort to deploy DTAG4s on humpback whales, including whales in four small groups that were suitable for caller-ID validation.

For higher-frequency species where the accelerometer method may not work well, other tools are needed. Here, the team is working on two model toothed whale species to validate different approaches that can be generalized for other priority species. In 2023, the team processed existing datasets for long-finned pilot whale social groups. The team also completed its first bottlenose dolphin field season in coordination with the Sarasota Dolphin Research Program.

In 2024, the team completed two successful field efforts, one in Sarasota, focusing on bottlenose dolphins, and another in the Stellwagen Bank National Marine Sanctuary, focused on humpback whales. The team completed a framework to understand the factors limiting accelerometer call detection in cetaceans. Analyses were completed to understand a range of these factors including accelerometer sampling rate and filters, system and ambient noise, and vibration coupling. Preliminary analyses were done to investigate how call properties affect vibra-

tion signals, and this will be expanded next year. The first analyses were also completed for bottlenose dolphin caller-ID identification.

Work planned for 2025 includes the last field season in Stellwagen Bank (humpback whales and fin whales). The team will also focus on completing and publishing validation results for humpback whales and toothed whales, and on further understanding the limits of different call identification methods.

This information will help the Navy's monitoring program with density estimates and understanding more on behavioral responses.

Project results will be shared through research papers, publications, analytical and data visualization methods for the DTAG toolbox and training materials to support broader use of validated methods.

This project will help to fill gaps in the ability to quantify individual and group-level cue rates, understand how cue rates depend on behavioral context and how vocal rates change as a function of disturbance. This information will help the Navy's monitoring program with density estimates and understanding more on behavioral responses.

About the Principal Investigator

Frants H. Jensen, Senior Researcher at Aarhus University in Denmark, has more than 18 years of experience applying sound and movement recording tags to investigate acoustic ecology of marine mammals and analyzing results using an array of software tools. His work has included developing new MATLAB® tools for analyzing multiple simultaneously deployed acoustic tags to identify focal vocalizations using cross-tag comparisons, and he has used DTAG4 accelerometers to detect throat vibrations associated with sound production in spotted hyenas. Dr. Jensen earned his Ph.D. in biology from Aarhus University.

Co-PIs are Susan E. Parks (Syracuse University, USA) and Douglas P. Gillespie (University of St. Andrews, UK).

Key contributors: K. Alex Shorter (University of Michigan), Dave Wiley (NOAA/Stellwagen Bank National Marine Sanctuary), Randy Wells (Sarasota Dolphin Research Program).

Publications

Zeh, J.M., Adcock, D.L., Perez-Marrufo, V., Cusano, D.A., Robbins, J., Tackaberry, J.E., Jensen, F.H., Weinrich, M., Friedlaender, A.S., Wiley, D.N. and Parks, S.E. (2024). Acoustic behavior of humpback whale calves on the feeding ground: Comparisons across age and implications for vocal development. *PLOS ONE* 19(5):e0303741. DOI 10.1371/journal.pone.0303741.

Zeh, J.M., Perez-Marrufo, V., Adcock, D.L., Jensen, F.H., Knapp, K.J., Robbins, J., Tackaberry, J.E., Weinrich, M., Friedlander, A.S., Wiley, D.N. and Parks, S.E. (2024). Caller identification and characterization of individual humpback whale acoustic behavior. *Royal Society Open Science*, 11(3):231608. DOI 10.1098/rsos.231608.

INVESTMENT AREA 3
MONITORING TECHNOLOGY DEMONSTRATIONS

LMR Investment Area 3 focuses on further development of technology to improve field data collection methods. Specific emphasis is given to utilizing existing Navy technologies and sensors for advancing data collection. These technology investments enable efficient and cost-effective implementation of the Navy's Marine Species Monitoring program in support of Navy at-sea compliance and permitting.

This investment area aligns with the goals of the Navy's Task Force Ocean to make every Navy platform a sensor for data collection. Advances in sensor technologies and platforms are increasing rapidly so it is important to continually integrate these new capabilities to reduce financial or operational constraints that impact the mission. In addition, investments by the LMR program in existing Navy technologies can have a return benefit to the operational community by demonstrating new system upgrades or advanced capabilities.

Projects in this area can include demonstrating and validating new monitoring technologies and platforms (such as sensors, tags, buoys, gliders and other autonomous unmanned vehicles).

The following section includes summaries of three ongoing projects and two new start projects.

Ongoing Projects

- Project 56—Integration and Field Evaluation of the Next Generation High-fidelity Sound and Movement Tags to Investigate Behavioral Response
- Project 57—Demonstrating Suction-cup Tag Systems to Support Behavioral Response Studies
- Project 59—Long-term Sparse Array Localization Feasibility Study using a SonarPoint System

New Start Projects

- Project 68—Thermal Imaging for Vessel Strike Mitigation on Autonomous Vessels
- Project 72—UUV Technology to Enable Readiness of Navy Ranges

MC1 Aaron T. Smith

Ongoing Projects

Integration and Field Evaluation of the Next Generation High-fidelity Sound and Movement Tags to Investigate Behavioral Response

Principal Investigator: Alex Shorter
Project Status: Ongoing, Project 56

NEED

N-0258-22: Demonstrate Existing Marine Mammal Tag Technologies

Marine mammal tag technology to collect marine mammal movement, diving and acoustic data was previously developed by the Office of Naval Research (ONR) Marine Mammals and Biology program and tags have been used in several LMR projects. However, tag technology is constantly evolving with tag redevelopment or modifications being made to address identified technological issues. Such new and modified configurations of developed tags need to be demonstrated to ensure their robustness for Navy marine species monitoring applications.

PROJECT

This project is focused on integrating next-generation electronics for high-fidelity sound and movement tags, a valuable asset for Navy marine species monitoring. Currently, tags are available to marine mammal research teams through a leasing system developed under the completed LMR Project 27 (see LMR 2021 Annual Report for information). This approach has expanded access to this technology and enhanced studies investigating acoustic response of marine mammals. To continue to support this effort, this project will integrate updated electronics into the tags, conduct dedicated beta testing of the systems to verify performance and develop training protocols for new users.

Work falls into three key tasks:

1. **Next-generation tag integration**

   Next-generation low-power tag electronics (DTAG4) will be used to enhance the performance of tags in the lease pool tag system. Because the new and smaller electronics will affect multiple subsystems of the tag package (e.g., floatation, VHS/GPS tracking, hydrodynamics and suction cups), this task is focused on engineering designs to accommodate the subsystem changes, prototyping and evaluation of the new designs.

   During 2023 and 2024, the project team has continued the work on design and fabrication of the tags. Changes made to the fabrication process have simplified the tag subsystems and reduced the time needed to assemble a finished tag. The latest tags are shown in Figure 1. Additional design improvements have been made to the tag subsystems based on lab/field testing and feedback from other tag users:

   - **Finishing**

     New paint and finishing approaches were used to improve the durability of the finishing coats used to create a highly visible tag for retrieval.

   - **Connector Assembly**

     The silicone pin cover design was modified to improve the seal at the connector during deployment to prevent connector pin corrosion. This included the design of a new mold to increase part yield.

   - **Release Assembly**

     The release assembly was redesigned to improve its field performance while also streamlining its production. This enables the release to be replaced if necessary.

   - **Releases**

     Tag releases were redesigned to improve the part manufacture process, reduce

fabrication time and improve reliable performance.

The new design is considered stable as of the end of 2024, but the team will continue monitoring results from the lab/field testing and feedback from customers.

2. **Lab-based and dedicated field testing**

The initial tag prototypes are used for lab-based testing to evaluate design performance and identify performance bounds for the system. Lab-tested tag designs are then tested in the field to characterize performance and identify design limitations under real world conditions. Field testing will include various species to investigate performance effects related to different whale sizes and behaviors. Target species include humpback whales, deep diving sperm, pilot whales and, if available, beaked whales and Risso's dolphins. Any issues identified during the field testing are being documented and cataloged to facilitate necessary design changes.

- **Lab Testing**

In 2023 the team investigated suction cup performance during hydrodynamic loading. The team tested tags at the Marine Hydrodynamics Laboratory at the University of Michigan using a cart system to generate flow speeds ranging between 1–4 m/s. Multiple tag orientations relative to the flow were measured to simulate tag placements that might be expected in the field. Data from these experiments were used to benchmark the hydrodynamics of the tag design, and to inform the requirements and specifications for the tag attachment system.

The team conducted acoustic testing at the Navy TRANSDEC (Transducer Evaluation Center) facility in Point Loma in September 2024. The goals included: 1) characterize the performance of the acoustic sensors on the tags, 2) measure any variability between tags, and 3) specify the directionality of the acoustic

Figure 1: Five tags fabricated during the first two quarters of 2024. A fully assembled tag with suction cups and release assembly is on the right.

measurements in the vertical and horizontal planes. Figure 2 presents a DTAG4 secured to the mounting structure in both the vertical and horizontal alignments at TRANSDEC. The team used two sound sources for the experimental measurements to characterize the low and medium frequency (20 Hz–20 kHz) response of the acoustic sensors. Before testing, a calibrated hydrophone (Type H52 Hydrophone) was used to evaluate the source level for each tone at its specific testing location.

Acoustic testing is planned to continue in 2025 at the Navy TRANSDEC facility.

- **Field Testing**

  The tag field testing was conducted in both 2023 and 2024. During 2023, the team worked with collaborators at the Stellwagen Bank National Marine Sanctuary to complete a holistic evaluation of the tagging system: deployment, attachment, release, recovery and measurement. All tags were successfully deployed and recovered during the field

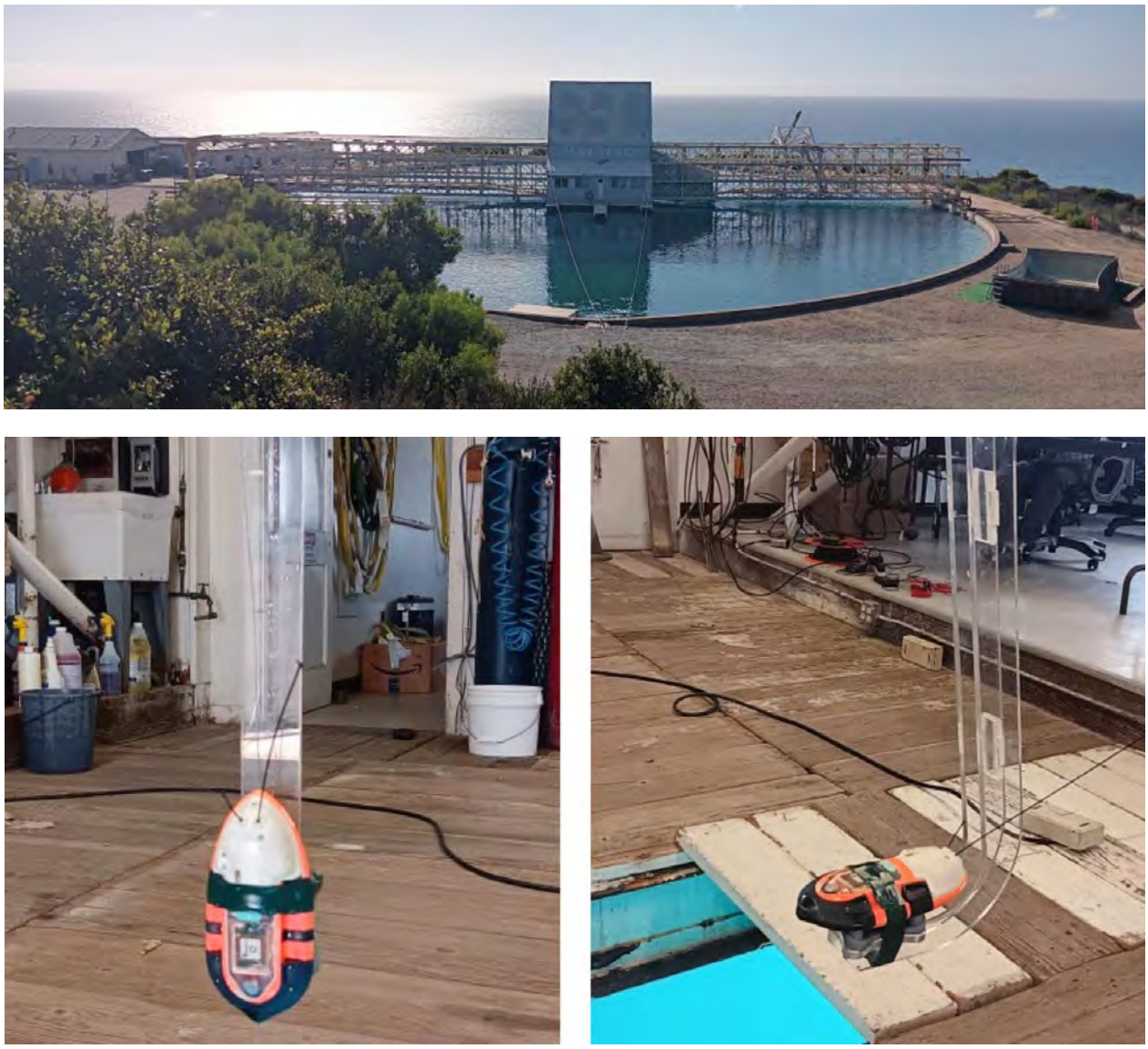


Figure 2: Top—Parabolic testing pool and testing facility at TRANSDEC.
Bottom—DTAG4 and custom mounting structure in vertical and horizontal alignments.
Access to the testing pool through the floor of the suspended testing house is visible at the bottom right.

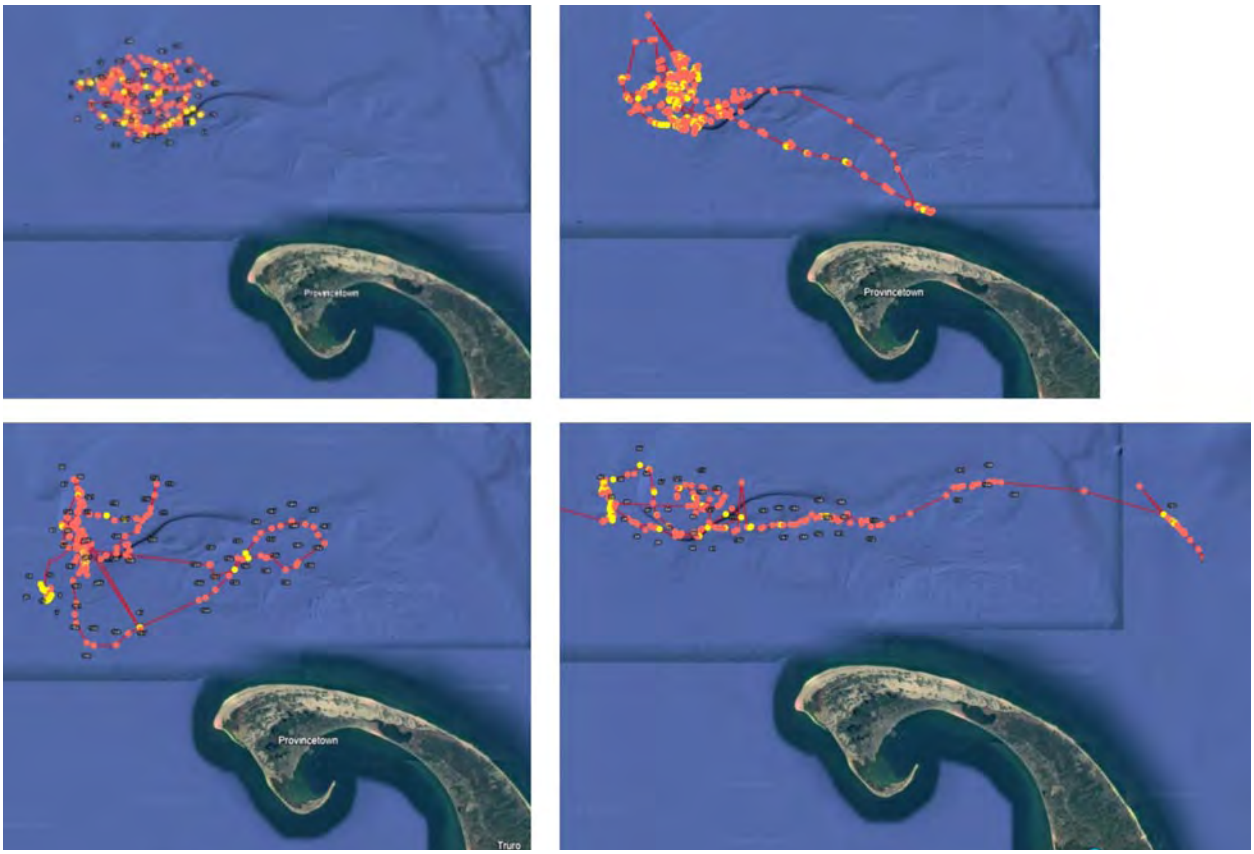


Figure 3: GPS tracks from four DTAG4 deployments on humpback whales at Stellwagen Bank National Marine Sanctuary.

effort. Twenty tags were deployed during the field work, with attachment durations ranging from 1 to 20 hours. All tags were recovered using a combination of Argos/VHF tracking.

During 2024, tags were field tested in Hawaii, the Azores and Stellwagen Bank National Marine Sanctuary. In all locations, the DTAGs included integrated Lotek modules for localization and recovery.

Hawaiian Islands Humpback Whale National Marine Sanctuary—Collaborators tested five DTAG4s over two 10-day efforts in January 2024. The tags were deployed on 14 animals, with each tag being deployed an average of 3.5 times. Deployment durations were typically between 1 to 10 hours, but one tag lasted over 30 hours. No tags were lost during the field effort. During recovery and tracking, an onboard goniometer/antenna received Argos signals at a range of approximately 10 nautical miles (nm), while VHF signals had a range of approximately 5 nm with hand-held Yagi antenna.

Stellwagen Bank National Marine Sanctuary—Collaborators deployed ten DTAG4s over two weeks in July 2024. Seven of the ten fabricated tags were deployed on 12 animals. Each of the seven tags was deployed an average of 1.5 times, and tags were set to release after 24 hours. A total of 173 hours of data were collected during the field work with tag deployments averaging approximately 12 hours. Three of the deployments lasted 24 hours. GPS tracks from four of the tagged animals are shown in Figure 3. No tags were lost during the field effort. An onboard goniometer/antenna to receive Argos

signals and a hand-held Yagi antenna to receive VHF signals were again used, enhancing the team's ability to recover the tags.

Terceira, Azores—Collaborators tested five DTAG4s off the coast in July 2024. The tags were successfully deployed on deep-diving animals (sperm, pilot and false killer whales) during the field effort. The team initially tagged four sperm whales and a pilot whale. The Azores team uses a unique and efficient tag recovery approach that takes advantage of the high island cliffs and multiple VHF listening stations. The team can hear the tags from more than 30 km and use bearings from multiple listening locations to estimate tag location. Subsequently the team was able to tag a false killer whale, and the deployment lasted longer than 30 hours. No tags were lost during the field work.

The field tested, next-generation DTAG technology will offer improved performance and data collection for Navy marine species monitoring efforts.

3. **Targeted support and training**

The project team will pilot in-person support to field users, develop operating procedures and guidelines to help users to integrate tags into their field effort, and create performance specifications for new tag features.

During 2024 the team worked to create user-friendly tools and guidance for individuals to better utilize the tags in the field. Specialized tools to facilitate the proper insertion and removal of the 'connector plug,' the suction cups and the tag releases were designed and fabricated to streamline the tag user experience. These tools are shipped with the tag to replace the user-supplied small hand tools previously used.

In addition, custom foam inserts for the Pelican cases used to transport/ship the tags were redesigned to accommodate the new tag tools and to improve production. Each case accommodates two tags, the 'robot' for pole-tag attachment, and the kit to support the tags (connectors, releases, cables, extra cups, custom tag tools, and hardware for the cup/tag interface). These tag cases include Apple AirTags as a secondary method of tracking the DTAGs when shipped.

The field tested, next-generation DTAG technology will be integrated into the existing tag leasing pool and will offer improved performance and data collection for Navy marine species monitoring efforts. The resulting technology will be applicable for both the deep-diving beaked whales and the large baleen whales that are priority species for Navy programs. The data that are collected with this tag technology supports Navy at-sea compliance and permitting.

About the Principal Investigator

Alex Shorter is an assistant professor in the University of Michigan's mechanical engineering department. He specializes in biomechanics and persistent monitoring applications for both people and animals. Shorter was one of the original DTAG engineers and has extensive experience with the design and fabrication of marine biologging tags. Dr. Shorter earned his Ph.D. in mechanical engineering from the University of Illinois Urbana-Champaign.

Demonstrating Suction-cup Tag Systems to Support Behavioral Response Studies

Principal Investigator: Patrick Miller
Project Status: Ongoing, Project 57

NEED

N-0258-22: Demonstrate Existing Marine Mammal Tag Technologies Investment Area
Monitoring Technology Demonstrations

Marine mammal tag technology to collect marine mammal movement, diving and acoustic data was previously developed by the Office of Naval Research (ONR) Marine Mammals and Biology program and tags have been used in several LMR projects. However, tag technology is constantly evolving with tag redevelopment or modifications being made to address identified technological issues. Such new and modified configurations of developed tags need to be demonstrated to ensure their robustness for Navy marine species monitoring applications.

PROJECT

Digital acoustic recording tags (DTAGs) have been a key technology for behavioral response studies (BRS). Multiple versions of these suction cup-attached tags have developed over years of field use. This project is working to demonstrate, maintain and iteratively improve the capabilities of existing state-of-the-art DTAG systems: (1) the integrated-DTAG system that includes DTAG electronics with GPS/Argos-VHF tracking capabilities (refined and produced through the lease pool at the University of Michigan under LMR Projects 27 and 56) and (2) the mixed-DTAG+ that includes a DTAG core unit (the electronic components of the DTAG) and other custom components in a larger combined housing to collect project-specific data.

The project efforts are focused on six key DTAG capabilities:

1. **Data quality**

   Systematically test DTAG core units to identify when failures occur and how to reduce their occurrence.

2. **Real-time tag tracking via GPS-Argos signals received by a goniometer (direction and distance estimation device)**

   Make and test changes to the goniometer antenna receiving system, the noise filtering systems in the antenna and the Argos transmit antenna to increase the reception range of tagged whales.

Frame of underwater video recorded from a mixed-DTAG+ deployed on a killer whale during the 3S3-2024 sonar trial. Herring prey and other foraging killer whales are clearly visible, demonstrating the ability of the video sensor in the mixed-DTAG+ to record fine-scale conditions near the tagged whale.

Mixed-DTAG deployed on a sub-adult killer whale, in the optimal placement for effective GPS tracking using the goniometer system.
Anna Selbmann, Iceland Marine and Freshwater Institute permit

3. **Argos-aided tag recovery**
   Evaluate how possible changes to the Argos transmit antenna could affect Argos transmission once the tag is floated after detachment.

4. **Suction cup retention times**
   Evaluate retention characteristics of different configurations of suction cup sizes and materials developed under LMR Project 21 (Extended Duration Acoustic Tagging of Right Whales; completed in 2021).

5. **Additional sensors**
   Evaluate two additional sensors on the mixed-DTAG+. One is a small video logger to enable observations of the prey field encountered by tagged whales; the second is a low-cost depth and acceleration logger as a backup device.

6. **Tag size**
   Create and test a smaller version of the current mixed-DTAG+ design for use with smaller animals (e.g., smaller killer whales and pilot whales).

The first field tests, co-funded with the French Directorate General of Armaments, were conducted in Iceland during 2022. Four mixed-DTAG+ devices with video and data sensors were successfully deployed on killer whales. The team also conducted goniometer decoding of GPS-Argos signals, using "boat-to-boat" tests to help clarify any performance issues, including evaluating the possible effect of ship noise on the transmission and reception.

The project achieved important progress and successes during 2023. Over the first half of 2023, efforts focused on designing an updated version of the mixed-DTAG+, specifically to include a newly designed wide-angle video and a 24-hour data logger produced by Little Leonardo (Capability 5). The updated version of the mixed-DTAG+ performed well during summer 2023 fieldwork in southern Iceland. The new video-data logger captured high-quality depth and acceleration data for 24 hours as a backup to the DTAG core unit (Capability 1) and

recorded clear wide-angle video sequences revealing complex feeding and social behaviors of tagged whales. The goniometer system for GPS tracking of the tagged whales exceeded previous performance, reliably providing near real-time GPS locations up to 9 km away. Extra tag flotation improved Argos signal reception during tag recovery (Capability 3), and suction cup retention times averaged 15.9 hours with a maximum of 24.8 hours (Capability 4), including several deployments on smaller killer whales (Capability 6). Based upon this positive outcome, the mixed-DTAG+ was used successfully in the 3S4 behavioral response trial in Norway (LMR Project 64, page 70) in October 2023, demonstrating the benefit of this project to behavioral response studies.

Project efforts will provide critical validation of and improvements to the mixed-DTAG+ and integrated-DTAG.

Work during 2024 built upon the 2023 progress, with a successful summer 2024 trial in southern Iceland. The team field-demonstrated a free and publicly available PAMGuard module ('pamgonio') to plot tracks generated using the real-time GPS-Argos tracking system plus optional visual observations (Capability 2). Both the mixed-DTAG+ and the integrated DTAG were field tested during the Iceland fieldwork with longer attachment durations (Capability 4) for the mixed-DTAG+ (22.8 hours), than the integrated DTAG (5.8 hours). Performance of the mixed-DTAG+ was strong for all other capabilities, and the mixed-DTAG+ was again used successfully in the 2024 field trial for LMR Project 64. With fieldwork now complete, efforts in 2025 will focus on writing and submitting the planned publications that will summarize project accomplishments. Updated housing units for the mixed-DTAG+ will also be produced in 2025, enabling future use of the mixed-DTAG+ in research projects.

Project efforts will provide critical validation of and improvements to the mixed-DTAG+ and integrated-DTAG, which are significant technologies supporting multiple Navy-funded marine mammal research and monitoring projects. Results of these types of studies provide valuable data for Navy at-sea compliance efforts.

About the Principal Investigator

Patrick Miller is a professor and senior research fellow at the University of St Andrews Sea Mammal Research Unit. Professor Miller has more than 25 years of cetacean research experience and 22 years of experience working on various behavioral response projects. He holds a Ph.D. in biological oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution joint program.

Key contributors: Filipa Samarra (University of Iceland), Alex Shorter (University of Michigan), Lars Kleivane (LKArts Norway).

Publication

Selbmann, A., Miller, P.J.O., Wensveen, P.J., Svavarsson, J. and Samarra, F.I.P. (2023). Call combination patterns in Icelandic killer whales (*Orcinus orca*). *Scientific Reports*, 3:21771. DOI 10.1038/s41598-023-48349-1.

Long-term Sparse Array Localization Feasibility Study Using a SonarPoint System

Principal Investigator: Marco Flagg
Project Status: Ongoing, Project 59

NEED

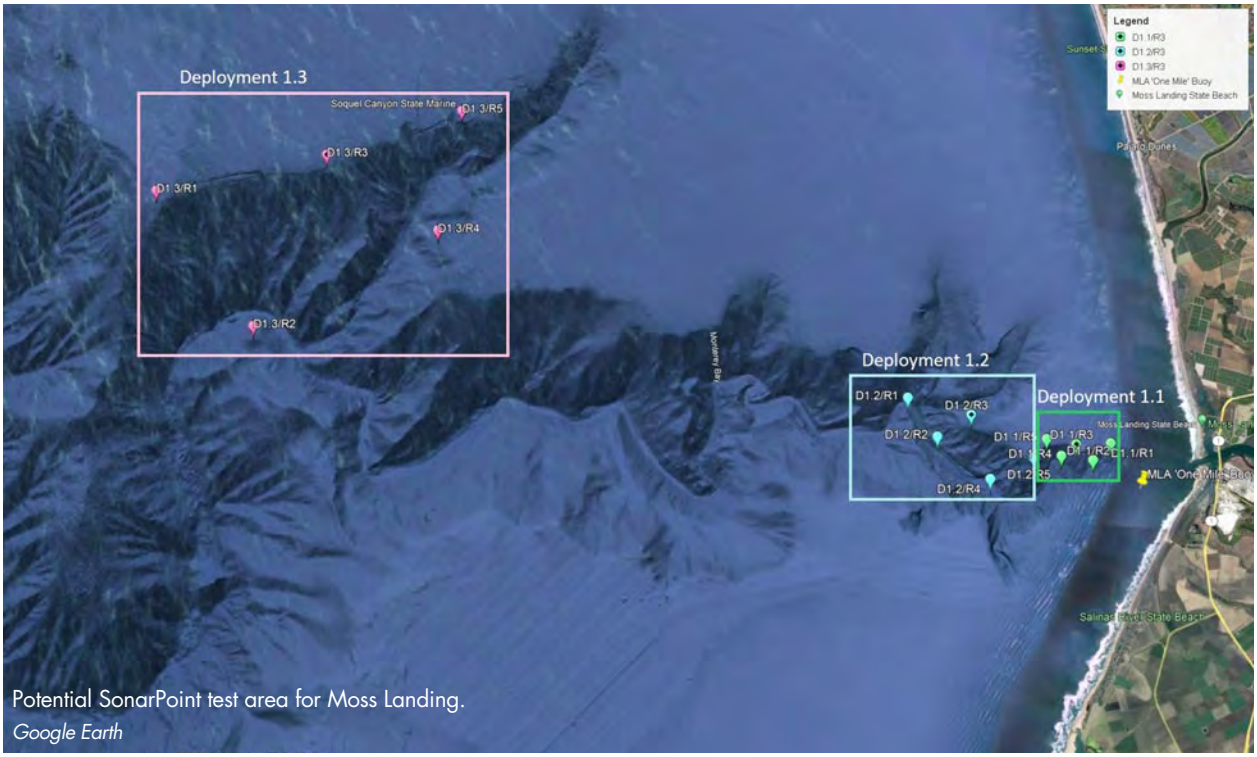
N-0257-22: Demonstrate and Validate the Ability of Existing Sparse Acoustic Array Technology to Address Navy Marine Species Monitoring Goals

Sparse acoustic arrays, in which sensors are distributed over a large area of interest, appear to offer cost effective passive acoustic monitoring (PAM) approaches to detect and localize marine mammals. The Office of Naval Research (ONR) Marine Mammals and Biology program investments have identified multiple promising systems of low-cost, easily deployed arrays for monitoring data collection. The practical utility and benefits of these existing systems for collecting data for Navy marine species monitoring applications now needs to be demonstrated in a Navy-relevant context against other existing technologies and methods.

PROJECT

This project is assessing the functionality and durability of SonarPoint—a sparse array system developed by Desert Star Systems—for detecting and locating a variety of marine mammal species. The modular SonarPoint acoustic recorder uses a time synchronization pinger and multiple recorders configured to detect and locate underwater sounds. Project efforts are focused on both validating localization capabilities and establishing methods and guidelines for successful localization strategies.

The project will conduct three stages of continuous recording (i.e., no duty cycling) deployments designed to explore and validate sparse array configurations. Multiple deployments will test the long-term operation of the recorders and evaluate increasing layers of resolution in the localization capabilities of the SonarPoint system. The work will demonstrate the practical boundaries of



Potential SonarPoint test area for Moss Landing.
Google Earth

sparse array operation in scale, array density, usable frequency spectrum (sample rate), depth dependency and endurance.

Phase 1 deployments will be a subset of three week-long deployments that vary in depth and inter-recorder distance. Two of these deployments were completed in 2023: Deployment 1.1 was at a depth of approximately 250 meters and Deployment 1.2 was at a depth of approximately 500 meters. The focus of these deployments was to 1) evaluate how recorder spacing affects localization results to determine maximum recorder spacing and 2) assess performance at increasing depth. Deployment 1.1 was performed successfully with the recovery of five recorders in May 2023. The dataset included acoustic detections of humpback whales, unidentified delphinids, transient killer whales, beaked whales and porpoises. The detection capability for high-frequency sounds with hydrophone spacing of 250–350 meters was evaluated by determining the proportion of echolocation clicks detected on each hydrophone across all acoustic events. Deployment 1.2 was conducted in August 2023 but only three of the five recorders were initially recovered. Several months later a fourth recorder was recovered, which enabled initial testing of localizing humpback whale vocalizations.

The release problem was analyzed during 2024. It ultimately was traced to the effect of depth on the release: more energy is required to fuse the release wire at greater depth. Work to address technical issues and improve recovery success for future deployments is ongoing. This includes acoustic release hardware upgrades, adding a duplicate acoustic release, and adding a satellite telemetry device to aid in recovery at the surface. Deployment 1.3 will occur in 2025 and involve a short-term deployment of five recorders at 1,000 meters to confirm that instrument performance and recovery methods are successful.

Depending on the success of Deployment 1.3, the Phase 2 deployment is planned for later in 2025 to demonstrate the long-term operation of the SonarPoint system and extensively evaluate the localization capabilities for a wide range of cetacean species. A larger array consisting of 12 recorders will be deployed at 1,000–2,000 meters for a long-term deployment.

SonarPoint mooring string.
Desert Star Systems

The Phase 3 final deployment will plan to use established Naval range hydrophone arrays to validate the SonarPoint system localization capabilities. This deployment also will provide an opportunity to train others on the system deployment, synchronization with pingers and system retrieval.

The data analysis component this project combines both semi-automated processing to determine periods of vocalizing marine mammals and subsequent localization to candidate acoustic events. The team is using PAMGuard (version 2.02.15) to process and annotate the datasets for all potential marine mammal calls. An initial exploration of the PAMGuard Group 3D Localizer for this task demonstrated that the tool (originally optimized for use with echolocating porpoises) might be less suitable for localizing large whale calls from sparse arrays. In 2024, the team evaluated a MATLAB-based tool, Where's Whaledo, which had success localizing beaked whales using tetrahedral arrays. This semi-automated tool allows for a different approach to localization that includes a user-interactive method for identifying

patterns in time-difference-of-arrival (TDOA) on hydrophone pairs within the array. The tool was modified to accommodate varied array configurations and required development of a detection approach for low-frequency baleen whale calls. Since the Deployment 1.2 dataset included adequate hydrophone spacing to assess humpback whale calls identified in the recordings, this species was used for initial evaluation and resulted in localizations. This analytical approach will be validated using data from the subsequent Deployment 1.3 and will involve further testing and evaluation with multiple species.

> Successful use of a sparse array within a monitoring area could provide an effective and lower cost option for the Navy's Marine Species Monitoring program.

In 2025, the team will evaluate an additional alternate localization method used for the Pacific Missile Range Facility (PMRF) site for data resulting from Deployment 1.3. An initial evaluation of humpback whale song suggested greater hydrophone spacing of 1–3 kilometers, at a minimum, is necessary for applying these methods. Adopting this methodology for baleen whales also provides the opportunity to obtain localizations with a well-vetted tool. For odontocetes, the project will also use the modified Where's Whaledo tool and continue to evaluate PAMGuard's Group 3D localizer for clicks. Deployment 2 will feature a nested array structure, including a shorter baseline (tighter) inner array and a longer baseline outer array. The inner array is expected to be more suitable for detecting clicks, which have a shorter detection range, and provide more precise TDOA measurements.

Analyses and reporting will be conducted after each deployment, with a final report completed in 2026. In addition to the final report, the project team will also provide the SonarPoint test system equipment and will produce a SonarPoint Sparse Array User's Guide and software to support system operation, signal detection and localization with SonarPoint.

This effort could ultimately support acoustic-based estimates of density, abundance and location of vocalizing marine mammals, specifically in locations beyond established Navy training ranges. The time-synchronized recorder array and software capable of handling large acoustic datasets will provide insight into localization capabilities and limitations of a sparse array. Successful use of a sparse array within a monitoring area could provide an effective and lower cost option for the Navy's Marine Species Monitoring program to monitor vocally active marine mammal species.

About the Principal Investigator

Marco Flagg is chief executive officer and principal designer of Desert Star Systems, which manufactures the SonarPoint system. Mr. Flagg's expertise includes acoustic positioning systems, acoustic releases, broadband recorders, acoustic modems and satellite reporting tags. Mr. Flagg and Desert Star Systems emphasize a combination of modular product design and strong field support and experience.

Key contributor: Elizabeth Ferguson (Ocean Science Analytics).

New Start Projects

Thermal Imaging for Vessel Strike Mitigation on Autonomous Vessels

Principal Investigator: Daniel P. Zitterbart
Project Status: New Start, Project 68

NEED

N39430-23-S-2503: Automated Detection of Marine Mammals for Unmanned Surface Vessel Strike Avoidance

The U.S. Navy is required under the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA) to mitigate any potential strike of large whales from a Navy vessel. The primary means of mitigation is to use lookouts to visually detect marine mammals at the surface to direct the vessel to avoid striking the animal. With Navy's ongoing development of new vessel technology such as medium and large displacement unmanned surface vessels, there is an increasing need for new methods of surface detection of marine mammals. The Navy seeks to demonstrate an existing thermal imaging system developed for the purpose of whale detection on a Navy unmanned surface vessel platform.

PROJECT

The project is focused on adapting and testing two existing and proven thermal imaging-based whale detection systems to reduce the potential for vessel strike during navigation of unmanned Navy surface vessels. The project team will build from two systems they have previously developed—WhaleDetect and WhaleID—to address specific Navy needs.

Following a four-phase approach, identified below, the project team will address key components of a detection system: mission-specific performance requirements, image stabilization, detection and classification algorithms, false alert rate and ultimate system effectiveness.

1. **Initial plan and design**

   The team will identify the list of relevant vessels, their maximum travel speeds and maneuvering capabilities as well as the species of

WhaleDetect system.
Daniel P. Zitterbart

interest. This information will be used to evaluate applicability of the existing vessel strike probability model to required performance parameters and reveal necessary adaptations. The team will evaluate existing thermal imaging components on Navy vessels to determine if existing equipment can be adapted.

2. **Development and initial field tests**

   The tests will quantify performance by comparing detection of visual observers to thermal imaging autodetection to the same cue. Experiments will include this dual platform approach to assess integrated system performance. The team will also assess whether the system outputs meet the interface requirements for the Navy vessel.

3. **Semi-autonomous system testing and performance evaluation in full integration configuration**

   This phase will still involve a human operator to assist with decision making. The team will integrate hardware and software into the vessel's command and control system followed by a multi-day test. Field tests will be designed to assess the performance of both the detection and autonomous evasive navigation capabilities. At the end of this phase a close-to-final version of the product would be installed on the Navy unmanned surface vehicle testing platform.

> The mutually beneficial result would protect both Navy assets and endangered whales by reducing the risk of whale strikes.

4. **System testing**

   This will be designed to meet full integration requirements on operational Navy unmanned surface vessels. During testing, the whale detection system would be continuously operated whenever the unmanned surface vehicle is in operation. Operational impact would be continuously monitored, and the

WhaleDetect 2025, the version of the automatic whale detection system to be tested in 2025. *Daniel P. Zitterbart*

physical condition of the system would be checked to assess its long-term usability and maintenance requirements.

Initial efforts are focused on Phase one, which will provide a plan and design for the project to proceed through the remaining outlined phases. During 2024 the team assessed the detection ranges needed to operate the technology on autonomous Navy vessels as well as the potential use of existing technology. The team determined there is no clearly defined thermal imaging system for future autonomous vessels that could be used as a hardware basis for whale detection. Furthermore, due to the high maneuverability of existing autonomous Navy vessels, the detection ranges that can be reliably achieved with the WhaleDetect system are sufficient.

Work in 2025 will focus on modeling the performance of the WhaleDetect system at speeds relevant to autonomous Navy platforms. In addition, the team will proceed with testing the existing WhaleDetect system on a Navy unmanned surface vessel to begin gathering data.

Ultimately, if successful, this technology would address an important requirement to allow for uninterrupted training and testing of unmanned surface vessels in areas where the potential for whale strikes to occur may be high. The mutually beneficial result would protect both Navy assets and endangered whales by reducing the risk of whale strikes.

About the Principal Investigator

Daniel P. Zitterbart is an associate scientist in the Applied Ocean Physics and Engineering Department at the Woods Hole Oceanographic Institution. Dr. Zitterbart earned his degree at the University of Erlangen-Nuremberg in Germany. His research interests include marine remote sensing and bioacoustics.

UUV Technology to Enable Readiness of Navy Ranges

Principal Investigator: Jeffrey Gilbert (Triton Systems, Inc.)
Project Status: New Start, Project 72

NEED

N193-148: Unmanned Underwater Vehicle (UUV) Technology to Enable Readiness of Navy Ranges

The Navy seeks to develop technologies to collect a broad spectrum of acoustic data that allows for large scale spatial and temporal research on ambient sources of sound and biologic vocalizations. The objective is to develop a passive acoustic monitoring (PAM) system to integrate with an unmanned underwater vehicle (UUV) to enable more cost-effective methods of monitoring marine mammal species of interest. The PAM system needs to provide the capability of calculating directionality of marine mammal signals within 30 degrees accuracy while consuming minimal power to increase system endurance. This technology will fundamentally change the methods of monitoring marine mammals by increasing the quality of acoustic data, increasing system endurance and lowering operational costs.

PROJECT

This project was initiated as a Small Business Innovative Research (SBIR) project. During Phase I (2020–2021), Triton Systems proposed initial design specifications for a Phase II prototype that would best address the need. The team evaluated potential UUV platforms and selected the Seaglider platform for testing its prototype. The Seaglider met most of the goals in the SBIR topic including long endurance, small form factor, low cost, easily deployed and sufficient payload capacity.

During Phase II (2022–2023), the team proceeded to develop and test its DIrectional Cetacean Acoustic Recorder (DICAR) featuring low-frequency and high-frequency acoustic receiver arrays to monitor marine mammal species of interest. The recorder can archive the data, with the potential future capability of running detection and classification software to enable transmitting detection events in nearly real time. Initial testing of the DICAR system in controlled aquatic settings demonstrated that it could provide directionality in the target fre-

Preparing for high-frequency testing at Chase Ocean Engineering Lab at University of New Hampshire.
Jeff Gilbert

Goose-beaked whale.

quency bands when integrated with Seaglider. Based on these results, the LMR program decided to co-fund an expanded Phase II with the SBIR program.

> This technology could increase acoustic data quality and support Navy marine mammal monitoring and density estimation efforts.

During the expanded Phase II (2024–2025), the team is focused on integrating the acoustic recorder into the platform, achieving proper balancing and ballasting of the platform with all components integrated, and completing two full engineering tests in a relevant setting. Field test goals include demonstrating both platform and recording technology performance. The team will assess the system's endurance and power management, as well as ability of the recorders and algorithms to differentiate individual calling animals.

A successful system could offer a cost-effective platform for extended surveying periods. Additionally, by providing relative position information, this technology could increase acoustic data quality and support Navy marine mammal monitoring and density estimation efforts.

About the Principal Investigator

Jeff Gilbert is an acoustic engineer in the Engineered Systems group at Triton Systems, Inc. where he has led a variety of research efforts for the Navy including development of a tactical oceanography training system, statistical methods to account for biological noise in anti-submarine warfare planning, and a quiet launch system for submarines deploying acoustic countermeasures. He brings a thorough understanding of computational acoustics and numerical simulation to the Triton team. He holds a Ph.D. in mechanical engineering from Boston University.

Key contributors: David Mellinger (Oregon State University), Holger Klinck (Cornell University).

INVESTMENT AREA 4 STANDARDS AND METRICS

LMR Investment Area 4 projects establish interagency and scientific community standards and metrics for data collection, management and analysis. This facilitates the information exchange needed to harness the capabilities of aggregated data, which supports Navy information dominance. Data that have been collected, managed or analyzed using varied techniques and methodologies can make it difficult to incorporate and use the information in the at-sea compliance process. For example, data pertaining to a particular species are often quantity-limited, making it necessary to aggregate data for multiple species that are often collected from a variety of sources. However, to aggregate data, the data need to be comparable, raising the need for agreement on standards and metrics.

Establishing interagency and scientific community standards and metrics for how data are collected, managed and analyzed promotes data comparability and enables data aggregation from different datasets. Ensuring consistent, agreed-upon standards and metrics provides multiple benefits, including cost-effective improvements to data, and results that can be utilized to establish policy and technical guidance. Projects in this area can include standards for data collection methods or standardized data management tools, as well as establishing metrics for reporting performance of data analysis methods.

The previous two projects in this investment area, Projects 46 and 66, were completed during 2024. Summaries for these projects are in the Completed Project section (see pages 47 and 60). No new projects were started during 2024.

Katie Archibald

INVESTMENT AREA 5 EMERGENT TOPICS

Investment Area 5 is reserved for other priority topics that are associated with emerging technologies or capabilities. This includes research needs that arise out of Navy at-sea compliance and permitting, or topics that do not squarely fall within the preceding categories.

No new projects were started during 2024.

MC1 Tyler Thompson

MC2 Nathan T. Beard

MC1 Steven Khor

Partnerships

The LMR program often works with other organizations on projects that offer benefits to Navy needs. Such partnerships help to leverage funding, expand demonstration and validation options, and draw on additional expertise.

The following section includes summaries of two ongoing partnerships.

- The Sonobuoy Liaison Working Group
- The Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life

Ongoing Partnerships

Sonobuoy Liaison Working Group

LMR continues to participate in and keep members of the Sonobuoy Liaison Working Group informed on the sonobuoy allocation for marine mammal research. LMR is responsible for determining which priority research projects receive available sonobuoys.

Projects and organizations receiving sonobuoys are

1. Hawaii marine mammal surveys—NOAA Pacific Islands Fisheries Science Center
2. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys—University of California at San Diego/Scripps Institution of Oceanography
3. NOAA Pacific Ocean Whale and Ecosystem Research (POWER) Survey—NOAA Marine Mammal Laboratory/Alaska Fisheries Science Center.

These sonobuoys are playing a significant role in expanding our datasets, and thus knowledge, related to where animals occur and when they are present.

Sailors prepare and inventory sonobuoys on the USS *Carl Vinson* (CVN 70).
MC3 Isaiah B. Goessl

The Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life

The Subcommittee on Ocean Science and Technology (SOST) Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML) partnership moved to a new level during 2019 when three projects were jointly selected and funded by five participating agencies.

Operating under the auspices of the National Science and Technology Council's Committee on the Environment, Natural Resources, and Sustainability (CENRS), the SOST advises CENRS on national issues of ocean science and technology and serves as the lead interagency entity for federal coordination on those matters. The SOST ITF-ONML was organized to increase coordination and communication across federal agencies in addressing issues related to the potential impacts of anthropogenic noise on marine life.

Five of the SOST ITF-ONML participants—the Chief of Naval Operations for Fleet Readiness and Logistics, Office of Naval Research, the Bureau of Ocean Energy Management, the National Oceanic and Atmospheric Administration, and the Marine Mammal Commission—partnered to jointly fund research on the auditory capabilities of mysticete whales. The group issued a call for proposals, via the LMR program, in July 2018 pertaining to development of audiograms for mysticetes. Following careful review and discussion by members of the review committee, three projects that covered a variety of methods were funded to increase the chance of success in obtaining data to address the need topic. The three projects are

1. Collection of AEP Hearing Thresholds in Minke Whales
2. Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds
3. Investigating Bone-conduction as a Pathway for Mysticete Hearing.

> Five of the SOST ITF-ONML participants partnered to jointly fund research on the auditory capabilities of mysticete whales.

Two of the three projects—Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales and Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds—have been managed by the LMR program. Summaries of these two, which were completed in 2024, are presented in this report on pages 22 and 26, respectively. The third project—Investigating Bone-conduction as a Pathway for Mysticete Hearing—is being managed by ONR MMB. Fact sheets for each of these three projects are available on the LMR website under the SOST Partnership tab.

Minke whale.

FORECAST

We look forward to even more accomplishments in 2025 and beyond. LMR will remain focused on meeting the Navy's need for research and technologies to sustain at-sea training and testing. Anticipated projects to meet the need include a behavioral response study to investigate the effects of explosive sources on marine mammals in Southern California waters as well as a pinniped behavioral response study to investigate how these animals respond to sonar to refine Navy impact estimates.

> We will continue to adapt and ensure that we are fulfilling our mission to support Navy readiness.

We will continue working towards Phase II of the SURTASS LFA (Surveillance Towed Array Sensor System Low Frequency Active sonar) behavioral response study. We will be focused on configuring an appropriate sound source to support the work. Phase II field efforts are expected sometime in 2027.

Each of the projects being considered was identified through our ongoing discussions with Navy end users to identify their most pressing research needs. These discussions will continue in the year ahead to reveal new need topics for LMR investment in 2026 and beyond.

To that end, we value the sustained coordination we have with the Navy's other research programs—ONR Marine Mammals and Biology (MMB) and the Navy's Marine Species Monitoring program—as well as with other programs, agencies and countries. Building on shared interests helps us all to effectively leverage investments and achieve common goals.

Reflecting on our ten years managing the LMR program, we are again reminded of how critical it is to be ready to adapt and address new challenges. We will continue, in the same spirit, to adapt and ensure that we are fulfilling our mission to support Navy readiness.

As always, this work ultimately is about our Sailors and our ability to maintain an effective and resilient Navy.

MC2 Jacob Mattingly

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Acronyms and Abbreviations

3S3/4 .....Sea mammals, Sonar, Safety project phase 3/phase 4
ABR.....Auditory brainstem response
ACCURATE.....ACoustic CUe RATEs for Passive Acoustics Density Estimation (project)
AEP.....Auditory evoked potentials
ANSI.....American National Standards Institute
AN/SQS-53C.....Computer-controlled surface-ship sonar
Argos.....A satellite-based system used for tracking data platforms (e.g., animal monitoring tags) in environmental monitoring
ARP.....Acoustic Recording Packages
ASA.....Acoustical Society of America
BOEM.....Bureau of Ocean Energy Management
BRS.....Behavioral Response Study
CalCOFI.....California Cooperative Oceanic Fisheries Investigations
CAS.....Continuous active sonar
CETACID.....Cetacean Caller-ID project
CEE.....Controlled exposure experiment
CENRS.....Committee on the Environment, Natural Resources, and Sustainability
CREEM.....Centre for Research into Ecological and Environmental Modelling
CTBTO IMS.....Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System
CW.....Continuous wave
DCL.....Detection, classification and localization
dB.....Decibels
DE.....Density estimation
DTAG.....Digital acoustic recording tag
ESA.....Endangered Species Act
FM.....Frequency modulation
GPS.....Global positioning system
HARP.....High Frequency Acoustic Recording Packages
ITF-ONML.....Interagency Task Force on Ocean Noise and Marine Life
ICI.....Inter-click intervals
IPR.....In-progress Review
kHz.....kilohertz
LIMPET.....Low Impact Minimally Percutaneous External-electronics Transmitter
LMR.....Living Marine Resources
LMRC.....Living Marine Resources Committee
M3.....U.S. Navy's passive acoustic marine mammal monitoring data system
MFAS.....Mid-frequency active sonar
MMC.....Marine Mammal Commission
MMPA.....Marine Mammal Protection Act
MSM.....U.S. Navy Marine Species Monitoring Program
NAEMO.....Navy Acoustic Effects Model
NEPA.....National Environmental Policy Act
NAVAIR.....Naval Air Systems Command
NAVFAC EXWC.....Naval Facilities Engineering and Expeditionary Warfare Center
NCEI.....National Centers for Environmental Information
NIWC.....Naval Information Warfare Center
NMFS.....National Marine Fisheries Service
NMMF.....National Marine Mammal Foundation
NOAA.....National Oceanic and Atmospheric Administration
NUWC.....Naval Undersea Warfare Center Newport
OBS.....Ocean Bottom Seismometers
OBIS-SEAMAP.....Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations
ONR.....Office of Naval Research
ONR MMB.....Office of Naval Research Marine Mammal Biology
OPNAV N4.....Chief of Naval Operations for Fleet Readiness and Logistics
PAM.....Passive acoustic monitoring
PAM-DE.....PAM-based density estimation
PAS.....Pulsed active sonar
PCoD.....Population consequences of disturbance
PI.....Principal investigator
PMRF.....Pacific Missile Range Facility
PTS.....Permanent threshold shift
RDT&E.....Research, development, test and evaluation
SAM tones.....Sinusoidal amplitude modulated tones
SBIR.....Small Business Innovative Research
SEL.....Sound exposure levels
SMRT.....Sound and motion recording and telemetry
SOAR.....Southern California Anti-Submarine Warfare Range
SOST ITF-ONML.....Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life
SPL.....Sound pressure levels
SYSCOM.....Systems Command
TB.....Terabyte
TRC.....Technical Review Committee
TTS.....Temporary threshold shift
UUV.....Unmanned underwater vehicle
VHF.....Very high frequency

Anu Kumar
Naval Facilities Engineering and Expeditionary Warfare Center
1000 23rd Avenue
Port Hueneme, CA 93043

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