LMR 2023

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

MAY 2024

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LIVING MARINE RESOURCES PROGRAM
ANNUAL REPORT

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Front and section cover photos: Lofoten Islands, Norway, site of the Project 37 2023 field effort.
Marine mammal photos that do not include a credit/permit number are from stock photo services.
Most headshots are by photographer Kenny Backer, Oxnard, CA.

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 6) offers a brief history of the program, summarizes how the LMR program supports the Navy's at-sea environmental compliance process and outlines how we collaborate with other Navy programs and federal agencies. These collaborative efforts have leveraged over $16 million of additional funding toward mutual benefit since 2014.

Program Manager Anu Kumar and
Deputy Program Manager Mandy Shoemaker.

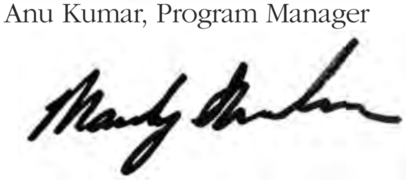
The Program Portfolio section (starting on page 20) includes background and updates on our many technical projects. In 2023, the LMR program was managing 31 Navy-funded projects, all carefully selected to meet specific Navy-defined needs and provide additional scientific credibility to the Navy's environmental compliance analysis. These 31 projects include four new projects, 18 ongoing projects and nine projects that were completed during 2023.

Products from the completed projects are being transitioned to the end users. The nine completed projects include three projects that provided *in situ* data on sound from explosive sources. Data from these projects provide new and important inputs to the Navy Acoustic Effect Model (NAEMO). Two other completed projects offer new insights into marine mammal hearing. Three projects are expanding the Navy's understanding of how to collect and use monitoring data to estimate animal density, behavior and responses. Lastly, with Phase I of the SURTASS LFA effort completed, attention here now focuses on identifying a sound source for Phase II.

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) environmental planners, regulators, scientists and other stakeholders. Twenty-five citations for 2023 publications are listed in the Publications section of this report (page 130). A list of 171 publications issued since 2013 is available on our website (exwc.navfac.navy.mil/LMR) under the Publications tab.

Thank you to 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 Advisory 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 relevant and foundational to the current and future Navy mission because of your involvement.

Anu Kumar, Program Manager



Mandy Shoemaker, Deputy Program Manager

OVERVIEW

Mission

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

The U.S. Navy supports both basic and applied research to improve the understanding of marine species in regard to occurrence, exposure, response and consequences. This research is needed to help reduce potential impacts to marine species and to bolster the Navy's at-sea environmental compliance and permitting processes.

The LMR program is responsible for the applied research and works both to address the Navy's key research needs and to transition the results and technologies to end users. LMR meets its mission and responsibilities by

- Improving the best available science, regarding the potential impacts to marine species from Navy activities, available for use in at-sea environmental compliance documentation
- Broadening the use of or improving the technology and methods available to the U.S. Navy Marine Species Monitoring program.

PROGRAM HISTORY

The LMR program traces its history back to the Navy's earliest efforts to better understand the impact of anthropogenic sound on marine mammals. In 1997, the scientific knowledge needed to establish an appropriate marine mammal monitoring and protection plan for Navy activities did not exist. To address this need, the Navy initiated the Marine Mammal Research program, managed by Dr. Frank Stone at what is now Chief of Naval Operations for Fleet Readiness and Logistics (OPNAV N4). The program partnered with other government agencies, universities and private industry to conduct scientific research required for monitoring and protecting marine mammals during Navy training and testing at sea.

Early on, Navy-funded research addressed broad study areas including marine mammal ecology and population dynamics, sound field characterization and monitoring methods. The research was targeted to provide a biological baseline that could be used when assessing the effects of Navy training activities on marine mammals.

Efforts were broadened in 2000 to include a new focus on the effects of mid-frequency sonar on beaked whales—the species thought to be most sensitive to that sonar. Between 2000 and 2007, the Navy began work to identify what information would be needed to obtain regulatory agency approvals for its major at-sea training ranges. In 2007, the research efforts were refocused to fulfill these information needs.

The LMR program's fundamental mission is to support the Navy's ability to conduct uninterrupted at-sea training and testing, which preserves core Navy readiness capabilities.

With a significantly expanded knowledge base, the distinctions among basic research (6.1 and 6.2 programs), applied research and testing (6.4

program) and the Marine Species Monitoring program became more well-defined. (For more on the distinctions among organizations responsible for marine mammal efforts, see our section, “Navy Programs That Enable Environmental Compliance” on page 9.) Thus in 2012, OPNAV N4 (formerly N45) transitioned the funding line and formally designated the LMR program as the 6.4 applied research, development, test and evaluation (RDT&E) program, and restructured it to address the Navy’s at-sea environmental compliance needs. While OPNAV N4 remained the resource sponsor, controlling the budget and final approval authority, the program needed dedicated management. A program office and manager were established at the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in Port Hueneme, California. This location allowed the program to manage and focus the increasing number of research needs, solicit and evaluate proposals, award contracts and provide end users the results they need.

With Dr. Robert (Bob) Gisiner as its first program manager, the LMR program took important first steps to establish the program’s new structure. This included setting up a program office, defining standard operating procedures, convening an advisory committee (the Living Marine Resources Advisory Committee (LMRAC)), issuing the first formal solicitation for research needs, and holding and documenting the first formal program review.

In June 2014, Anu Kumar was hired as program manager, following Bob Gisiner’s retirement. Mandy Shoemaker was selected to fill the deputy program manager position. The new team brought complementary skills and experience as subject matter experts in the Navy’s environmental compliance process and associated scientific needs to carry the program forward. They have continued to refine the research needs evaluation and contract management processes to ensure that funds are efficiently expended on those projects of highest priority to the Navy. They have emphasized a collaborative atmosphere among the principal investigators executing the research and have enhanced end user involvement in the research products to ensure that those products address the original need. They also have continually worked to strengthen interagency and international coop-


MC3 August Clawson

eration, leveraging resources across related programs, and optimizing limited funding resources (see the "Coordination/Collaboration with Other Programs, Agencies and Research Institutions" section on page 16 for examples). The highest priority is to transition successful products to the Navy's at-sea environmental compliance process in support of ensuring the uninterrupted training and testing needed for a combat-ready force.

NAVY READINESS DEPENDS ON ENVIRONMENTAL COMPLIANCE

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 environmental laws and regulations such as the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA).

> Environmental compliance 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 environmental permits to conduct activities that may result in impacts to protected species regulated under environmental 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 and associated environmental compliance, the Navy risks not being able to train or test. Without training and testing, the Navy cannot be ready to meet its mission. Environmental compliance is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

NAVY PROGRAMS THAT ENABLE ENVIRONMENTAL COMPLIANCE

The U.S. Navy funds three main programs to support at-sea environmental compliance needs. 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 the three programs, the program manager from ONR MMB and representatives from the MSM program are members of the LMRAC (described on page 12).

Seaman Guadalupe Barragan Arenas

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 transitioned 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 transitioned directly to the Navy MSM program 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 the Navy's at-sea environmental compliance community. As a 6.4 late stage applied research program, LMR develops, demonstrates, validates and assesses the data, methods and technology solutions needed to study protected living marine resources that may be affected by training and testing activities.

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:

- Collect and evaluate data on hearing abilities of marine species.
- Conduct research on species groups other than marine mammals (e.g., fish, sea turtles, birds).
- Anticipate and conduct research on potential impacts resulting from new Navy sources (e.g., continuous active sonar).

- 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 environmental compliance. 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.

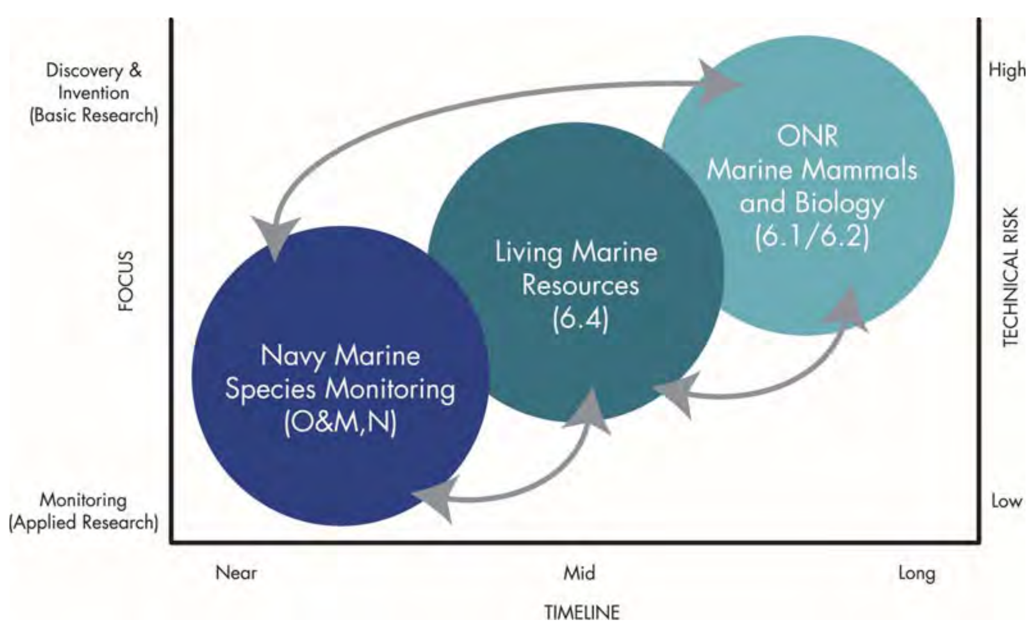
U.S. Navy Marine Species Monitoring Program

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 chart below 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 transition to the next stage of 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 environmental 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.



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 environmental permits and ensure uninterrupted training and testing.

> There is significant interplay of projects and support among the three programs, yet each serves a distinct role in the compliance process.

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.

Advisory Committees

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

LMR Advisory Committee

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

LMRAC 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 transition pathways.

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 environmental 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 transitioning solutions into the Navy's at-sea environmental compliance process. 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/collaboration 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 environmental compliance and permitting process, 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 and to determine appropriate mitigation measures to reduce impacts to protected marine species. 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.

MC2 Evan Diaz

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 environmental research and data collection. These technology investments enable efficient and cost-effective implementation of the Navy's MSM program to support the Navy's environmental compliance and permitting processes.

   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 data sets. Ensure consistent, agreed-upon standards and metrics in order 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 environmental compliance process, or topics that do not squarely fall within the preceding categories. In 2023, we did not have any investments within emergent topics.

For details on submitting needs, see the program website at exwc.navfac.navy.mil/lmr.

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 research challenges faced by the Navy at-sea environmental compliance community to provide solutions that will reduce operational constraints.
- Identify an existing gap in knowledge, technology and/or capability in order to provide flexibility to the Navy to achieve the mission.
- Fulfill an environmental constraint or regulatory 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 LMRAC, 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.

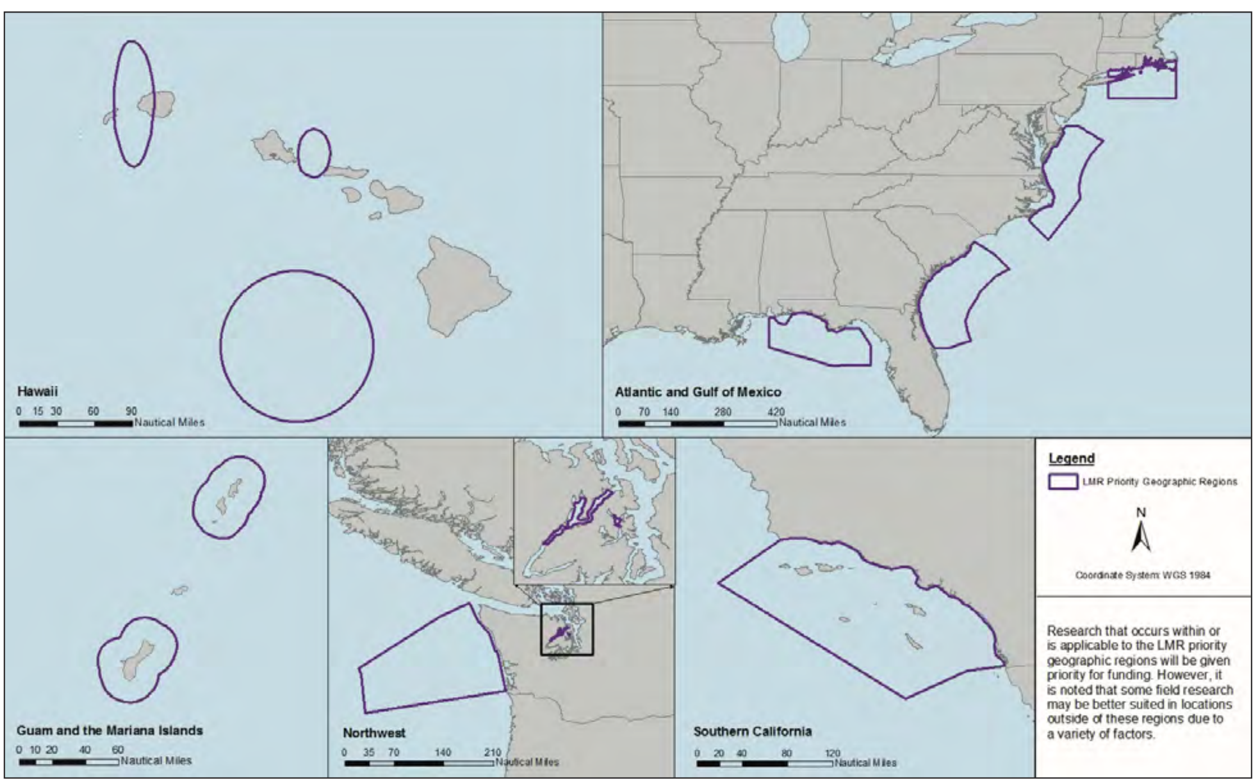
Priority Species and Geographic Regions

In addition to the program investment areas and the identified needs, the program also considers priority species and geographic regions when evaluating and ranking proposals for program funding. While the program is interested in increasing knowledge and understanding of all marine mammal species, projects must be considered within the program's budget. To provide some guidance on research priorities, the priority marine mammal species for the program include

- Deep-diving species (beaked whales, sperm whales and other deep-diving species)
- ESA-listed species.

In addition to marine mammal species, the LMR program has funded projects that are increasing knowledge and understanding of the potential impacts to sea turtles, diving sea birds and fish in response to specifically identified priority Navy needs.

The LMR program is primarily interested in funding research that is applicable to geographic regions that are important to the U.S. Navy. The map below shows the LMR program priority geographic regions. It is important to note that the LMR program acknowledges that a variety of factors could



LMR priority geographic regions.

lead to some field research being conducted outside of these geographic regions, although results still apply to Navy needs within the regions.

Coordination/Collaboration with Other Programs, Agencies and Research Institutions

The program makes a concerted effort to continually expand and strengthen our network of partners, which is the fourth line of effort described in the Navy's Design for Maintaining Maritime Superiority (Version 2.0). The program does this by

- Maintaining close alignment across the U.S. government, including partnerships with agencies such as National Oceanographic and Atmospheric Administration (NOAA), Marine Mammal Commission (MMC) and Bureau of Ocean and Energy Management (BOEM)
- Advancing the Navy's partnership with industry through Broad Agency Announcements (BAAs) and Small Business Innovative Research (SBIR) efforts
- Enhancing cooperation with academia; we currently partner with roughly 15 academic and research institutions.

An example of multi-agency coordination is LMR's active support to the Subcommittee on Ocean Science and Technology (SOST). The SOST's purpose is to advise the National Science and Technology Council's Committee on Environment, Natural Resources and Sustainability on national issues of ocean science and technology, and to serve as the lead interagency entity for federal coordination on those matters. One component of SOST is the Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML), formed to increase coordination and communication across federal agencies in addressing issues related to the potential impacts of anthropogenic noise on marine life. The SOST ITF-ONML issued a call for pre-proposals via the LMR program in July 2018 pertaining to development of audiograms for mysticetes. The LMR program is currently managing two of the three projects chosen from the preproposals. These two projects, Collection of AEP Hearing Thresholds in Minke Whales, and Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds, are summarized on pages 54 and 58, respectively.

> The program makes a concerted effort to continually expand and strengthen our network of partners.

The LMR program is also expanding partnerships with industry through the SBIR program, which provides an opportunity for domestic small businesses to engage in federal research and development that has the potential for commercialization. The research topic submitted by LMR, Unmanned Underwater Vehicle (UUV) Technology to Enable Readiness of Navy Ranges, seeks technologies that can collect a broad spectrum of ocean acoustic data to support large-scale spatial and temporal research on ambient and biological sources of sound. The following three companies participated in Phase I:

1. Triton Systems
2. OASIS (now part of ThayerMahan)
3. EOM Offshore.

After the completion of Phase I, LMR selected Triton Systems for a Phase II, which went through Fall of 2022 with an option to extend. At the end of Phase II, Triton was eligible for and was awarded an additional Phase II option in December 2022. The Phase II option, which will go through early 2024, includes integrated systems bench testing. If results are successful, the LMR program will determine whether to proceed with jointly funding a second Phase II option effort to conduct in-water testing and field demonstration.

A subsequent SBIR project has progressed with NOAA's Office of Law Enforcement (OLE). The OLE was interested in partnering with LMR to pursue the technology from OASIS/ThayerMahan for a technology development effort to detect illegal fishing activity in the waters within the United States Economic Exclusion Zone. This led to an OLE contract with ThayerMahan and Ocean Aero to develop an integrated device capable of visually and acoustically detecting, locating and reporting illegal fishing activity. The project includes work by the Naval Research Laboratory (NRL) to integrate the data streams coming from the Thayer Mahan/Ocean Aero system into NRL's global maritime domain awareness system, PROTEUS. The NRL portion is funded by LMR. The overall integrated system could also be used to detect and locate marine mammals and thus support the Navy marine species monitoring program in the future. The first field test is scheduled for Fall 2024 in the Flower Garden Banks National Marine Sanctuary.

These projects have leveraged over $16 million in external funding.

Since 2014, LMR has managed 14 projects that involve coordination with outside organizations. These projects have leveraged over $16 million in external funding. Of this leveraged funding, thirty-one percent ($5.12 million) has come from other Navy programs (e.g., ONR and SBIR) and the other sixty-nine percent ($11.35 million) has come from outside the Navy. In addition to funding benefits, these projects build a knowledge base and relationships with other agencies that increase mutual awareness of needs and potential changes in criteria, technologies and methods that could affect Navy activities.

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 BAA for offerors that are outside the federal government. After the solicitation closing date, the proposal evaluation process—conducted by the LMRAC, TRC and program staff—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 staff to discuss project and program expectations. Discussions cover details such as project milestones, spending plan and financial expectations, reporting requirements and ongoing communication with program staff. The goal is to establish a framework that promotes project success and keeps projects targeted on meeting Navy needs.

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 goals and program 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. Subscribers are notified by email when a new issue is available.

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 2023, the spreadsheet list included 171 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.

For the latest spreadsheet, go to exwc.navfac.navy.mil/lmr and click on the Publications tab.

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 quarterly. 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
- Transition steps
- Information about the principal investigator(s).

In-progress Review

Each principal investigator is required to provide a technical briefing to the LMRAC 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

Nine projects were completed during 2023 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 environmental compliance.

The completed LMR projects are

1. Project 26—Effects of Underwater Explosions on Fish
2. Project 35—Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources
3. Project 43—MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance
4. Project 44—Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales
5. Project 48—Collection of *in situ* Acoustic Data for Validation of Navy Propagation Models of Ship Shock Trial Sound Source
6. Project 55—Dolphin Conditioned Hearing Attenuation
7. Project 58—Bryde's Whale Cue Rates and Kinematics
8. Project 61—Auditory Masking in Odobenid and Otariid Carnivores
9. Projects 52, 53 and 54—Studying Marine Mammal Behavioral Response to SURTASS LFA Sonar.

LMR Projects

The Effects of Underwater Explosions on Fish

Principal Investigators:
Peter H. Dahl, Keith Jenkins
Project Status: Completed, Project 26

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 data on the effects of explosives on fish in order to update risk threshold criteria, reduce the uncertainty of the current impact assessments and validate mitigation measures.

PROJECT

U.S. Navy training and testing activities can include underwater explosive charges and additional data are needed regarding the effects of such explosives on fish. A multidisciplinary team of researchers designed and conducted field-based experiments to collect data needed to develop guidelines and threshold criteria for effects on fish resulting from exposure to underwater explosives.

The project team studied explosive effects on fish species with differing characteristics (e.g., swim bladder morphology) and size, at varied water depths and distances from the source. Tissues from exposed fish (as well as from an extensive

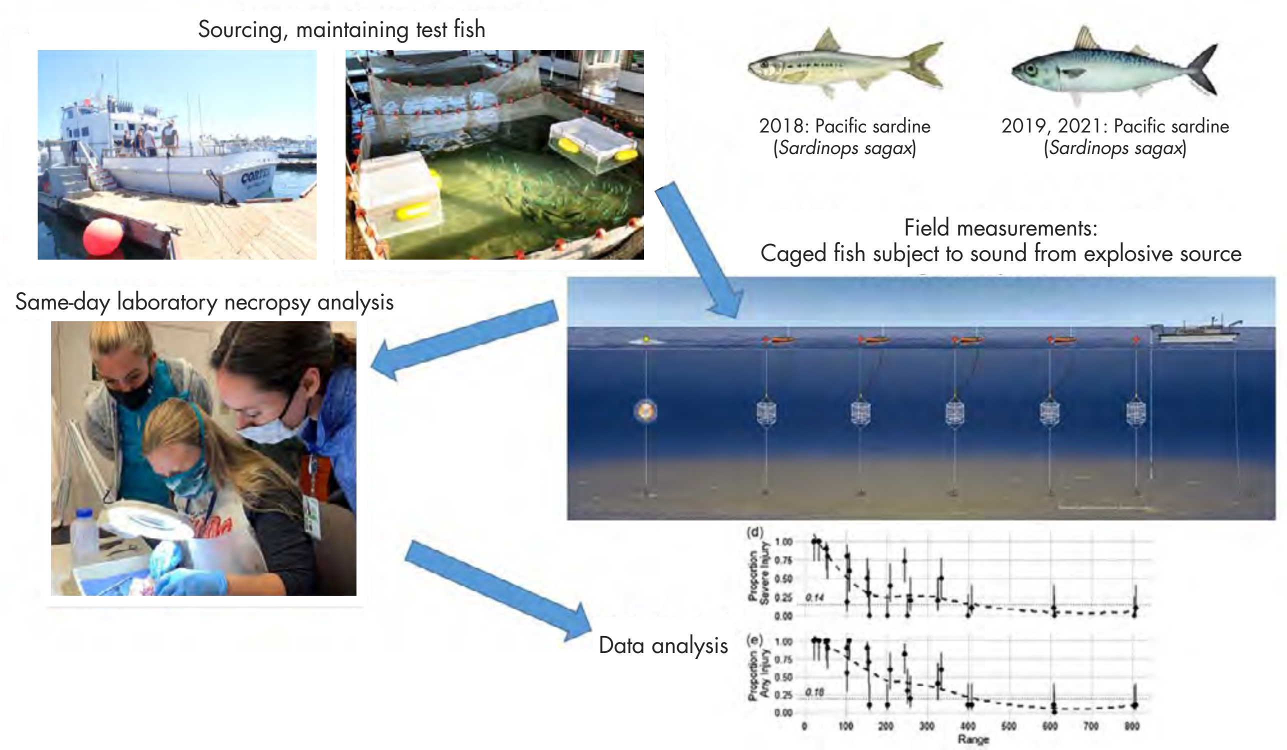


Figure 1: Basic overview of approach used in 2018, 2019 and 2021. The approach involved four primary phases: (1) sourcing and maintaining test fish, (2) field measurements, (3) same-day laboratory necropsy analysis and (4) data analysis.

set of control samples) were examined using well-established necropsy techniques. Careful attention was focused on ensuring a statistically valid experimental design. This approach was taken to provide a broader and more comprehensive understanding of potential effects and dose-response relationships. Figure 1 provides a general overview of this approach, which was used for each of the three field studies completed in 2018, 2019 and 2021.

The Phase I trials were completed in 2018 and used Pacific sardines (*Sardinops sagax*), held in cages deployed at 10 meters depth at multiple distances from the explosive source. Results from those trials were presented in 2019 at the *Effects of Noise on Aquatic Life* conference in The Netherlands.

Phase II trials were conducted during September 2019 following protocols and experimental design informed by the 2018 study. In this case a second species, Pacific mackerel (*Scomber japonicus*), represented a slightly larger species and different morphology. Drawing upon Phase I results, necropsy and ear tissue preservation techniques were modified to help to refine Phase II results.

The first project manuscript was published in 2020, which covered the Pacific sardine data under the Phase I trial in 2018 (see Publications sidebar). Also, during 2020, the team focused on analyzing 2019 mackerel data collected during the Phase II trials, which suggested different outcomes between the sardines from 2018 and the mackerel, despite similar test conditions. Factors contributing to these differences could include different acoustic propagation conditions between trial years and morphological differences between the two species (Figure 2).

Phase III trials, originally planned for 2020 and delayed due to COVID-19 restrictions, were completed in October 2021. The 2021 event again used Pacific mackerel. Wild sardines were also

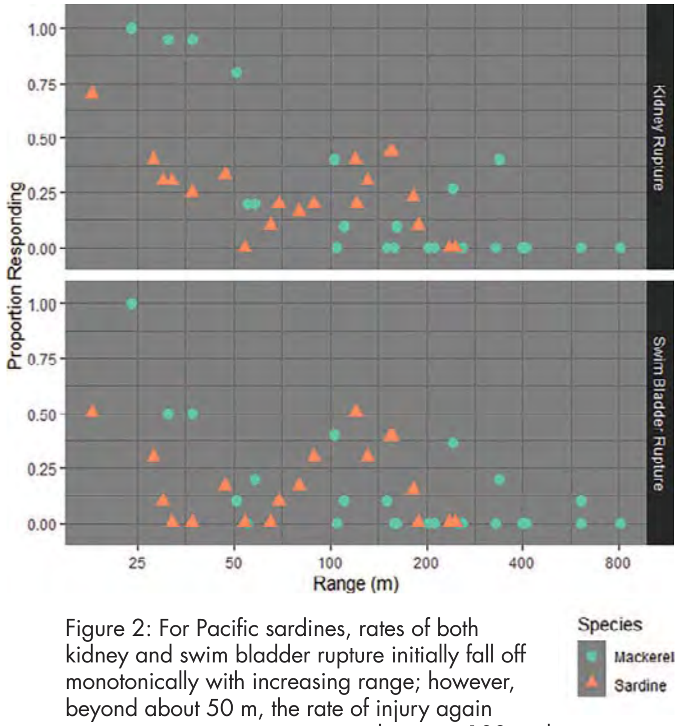


Figure 2: For Pacific sardines, rates of both kidney and swim bladder rupture initially fall off monotonically with increasing range; however, beyond about 50 m, the rate of injury again increases, attaining a maximum between 100 and 150 m. This was not the case with Pacific mackerel where injuries decreased across the entire range.
From Jenkins et al *(2023)*

collected when they were discovered floating near the point of detonation immediately after the explosion. This final round of testing benefited from refined fish handling protocols, which were improved after each of the preceding field efforts. The team was able to investigate short-term survival after the explosion, onset of injury at a finer scale than the previous two trials and obtain some preliminary findings on the effect of depth.

Work during 2022 included two publications reporting on results from the 2019 Pacific mackerel Phase II trials. One focused on non-auditory effects and the other focused on analyses of ear tissues (see Publications sidebar). Additionally, the results from all three trials (Phases I-III) were presented in 2022 at the *Effects of Noise on Aquatic Life* meeting in Berlin, Germany.

During its final year, 2023, the project completed data analyses and its third publication.

Mackerel.

The final publication scheduled for 2024 will report on results from the 2021 Pacific mackerel trials (Phase III), including relevant comparisons with Phase I (2018) and Phase II (2019) trials.

The results of this applied research and accompanying criteria will be immediately useful within the Navy environmental compliance process.

The results of this applied research and accompanying criteria will be immediately useful within the Navy environmental compliance process when quantifying potential explosive impacts to fish.

About the Principal Investigators

Peter H. Dahl is a senior principal engineer in the acoustics department at the University of Washington Applied Physics Laboratory, and professor in the University of Washington's Department of Mechanical Engineering. Dahl's research is in areas of acoustics with a primary focus on underwater sound. Dr. Dahl earned his Ph.D. from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution.

Keith Jenkins is a senior marine resource specialist at Naval Information Warfare Center Pacific. He has been conducting acoustic analyses for the Navy for almost 20 years and participates in developing Navy-wide acoustic effects criteria and thresholds. Mr. Jenkins has a B.S. and M.S. in biology from Old Dominion University, Virginia.

Key collaborator: Art Popper (University of Maryland).

Publications

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Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources

Principal Investigator: Peter H. Dahl
Project Status: Completed, Project 35

NEED

N-0159-18: *In situ* Explosive Sound Characterization and Propagation Data Collection and Analysis

The Navy models the effects of explosive detonations to determine the potential impacts to marine species (mammals, sea turtles, fish and birds). The current models are validated using *in situ* data recorded for a small subset of the types of munitions—largely data from small explosive charges in shallow water depths—that the Navy could use in training and testing activities. These data may not fully represent the sound source characteristics and propagation conditions that could be generated by larger size charges in more variable training and testing environments. Therefore, the Navy seeks to collect additional data on a broader range of charge sizes and at a variety of distances/depths to improve the validation of the Navy's Acoustic Effects Model (NAEMO) explosive propagation, and to ensure that predictions of effects to marine species are as accurate as possible.

PROJECT

This project was established to conduct a set of well-documented and calibrated underwater acoustic field measurements associated with explosive detonations near the water surface. It included measurements at both very close range and longer ranges that are influenced by multiple reflections from the sea surface and seabed, changing bathymetry and sound speed conditions. Results will be used to update NAEMO, which simulates potential impacts on marine species.

Originally funded in 2018, COVID-19 pandemic restrictions and associated difficulties coordinating opportunities with Navy range testing delayed its start. Field tests planned for 2020 and 2021 were canceled, slowing progress on the original goals of this project.

During 2021, however, a task was added to this project in support of the Navy's full ship shock trial (FSST). Project team members from the Applied Physics Laboratory (APL) were tasked with providing one of the environmental teams on the FSST with a portable device for measuring the explosive signal. Specifically, the APL team assembled an easy-to-use portable sound recording package capable of recording high-intensity acoustic fields from explosive sources and trained personnel on an environmental support vessel to deploy and retrieve it.

Results will be used to update NAEMO, which simulates potential impacts on marine species.

Work in 2022 focused on completing data analyses that included existing oceanography data for the area and measurements taken during the FSST. Following analyses and full quality control checks, the team transferred data to the NAEMO group. The results will complement recordings taken in the broader effort under Project 48, Collection of *in situ* Acoustic Data for Validation of U.S. Navy Propagation Models of Ship Shock Trial Sound Sources (page 37), which the NAEMO group will be analyzing.

Additionally, in 2022 the LMR program managers coordinated a team to include the University of Washington, the Naval Research Laboratory, NAEMO experts and a Navy explosive ordnance disposal team. This new team developed a revised plan for achieving the project goals with data from smaller detonations than originally planned.

In summer 2023 an experimental field effort was successfully conducted off the coast of San Clemente Island. The experiment called for the measurement of the underwater acoustic field from a series of detonations. A total of six detonations were conducted, ranging in size from 10 to 40 pounds (C-4 explosive). All detonations were carried out by a Navy explosive ordnance disposal team (EODMU3 DET SW). For each detonation, the C-4 was tethered to a buoy, designed to sit just below the water surface (roughly 25 cm). The overall depth of the water at the study site was approximately 1,300 meters. During the detonation phase of the experiment two marine mammal observers stationed on the research vessel (R/V *Diane G*) monitored the mitigation zone. No marine mammals were visually observed.

As a bonus, an animal tagging component was added and carried out by members of Marine Ecology and Telemetry Research. They were tasked with tagging as many animals as they could in the days leading up to the field test. In total, they were able to tag two fin whales, two Cuvier's beaked whales and a blue whale. These data will be analyzed for any potential behavioral reactions to the explosive detonations as part of a new project that will begin in 2024.

An overview of the trial (Figure 1) shows experimental geometry in terms of measurement range and depth for four acoustic measurement stations identified as 0, 1, 2, 3. The exact location of receiving stations 1–3 was determined by a GPS device mounted at each acoustic measurement station. This information was then used in combination with the location of the explosive source buoy (upper left) at the time of each detonation, which was determined by sacrificial GPS devices. The range and depth data as shown represent actual depths as determined post-experiment. The measurement range shown for station 1 (e.g., 85–110 m) reflects the small variation of the source location for each new detonation. For station 1, the

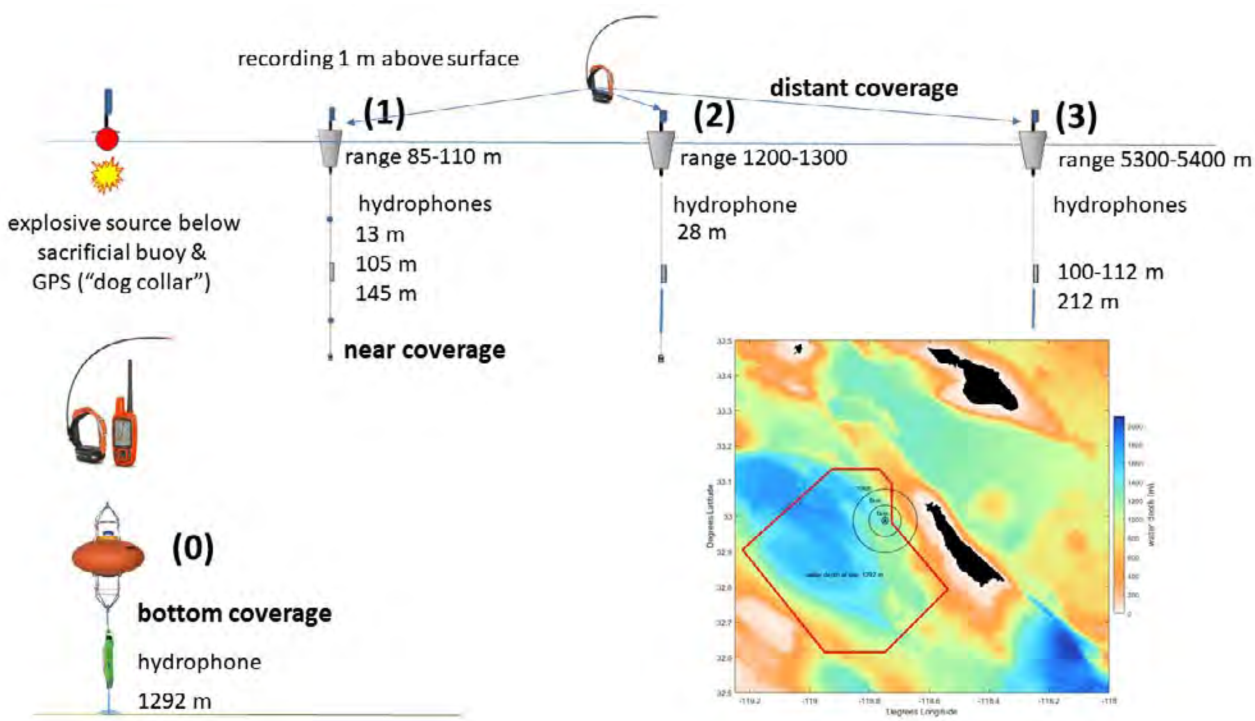


Figure 1: Experimental geometry for the 25 July trial based on four measurement stations identified as 0, 1, 2, 3 and explosive source station (upper left). A planned location identified the explosive source station with the exact location at the time of each detonation determined by a sacrificial GPS device. Plan view of the experimental area (lower right) shows location west of San Clemente Island.

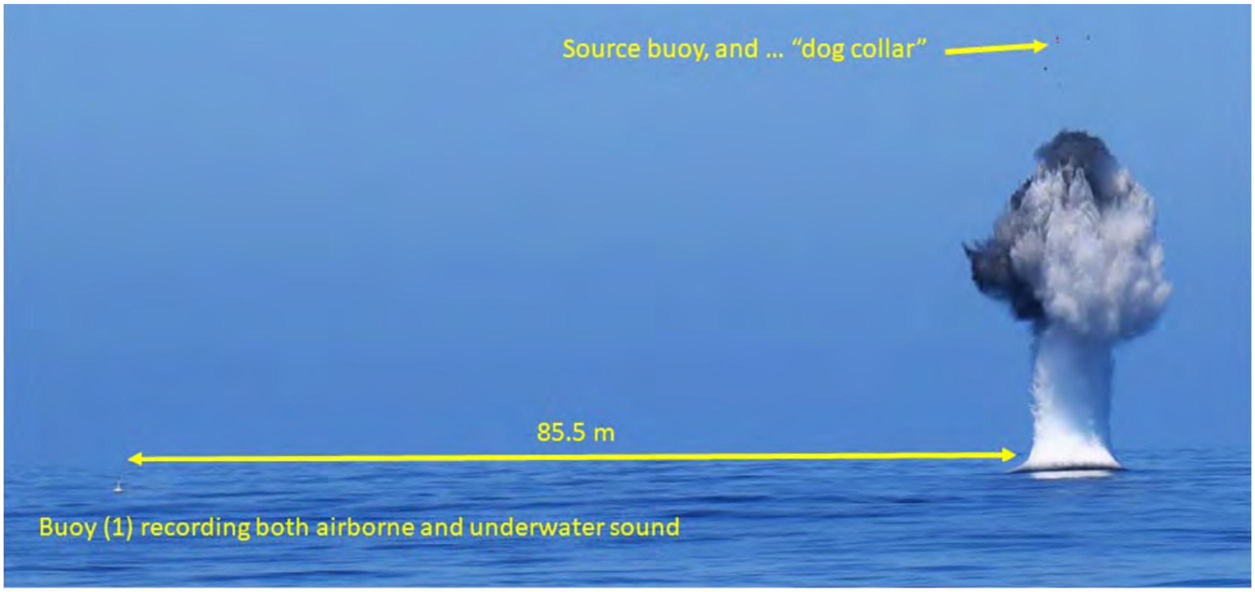


Figure 2: Photo captures the exact instant of the detonation of a 40 lb. C-4 explosive. 0Measurement station 1 is seen 85.5 m from detonation. The source location was determined by a sacrificial GPS system. Remnants of the explosive source buoy and GPS unit can be seen in the air (approximate height of 50 m).

Mandy Shoemaker

goal was to try and keep that station roughly 100 meters from the explosive source (Figure 2). Measurement stations 2 and 3 were designed to drift over the course of all the detonations, which provided a variety of measurement distances.

The data collected directly apply to improving the accuracy and verification of NAEMO-based predictions of underwater sound fields from explosives.

In summary, the July 2023 field trial produced a calibrated dataset of underwater acoustic recordings of six near-surface explosions measured at a variety of ranges and depths. The dataset included environmental and meta data necessary for the NAEMO team to compare these results to the NAEMO modeling results. The data collected directly apply to improving the accuracy and verification of NAEMO-based predictions of underwater sound fields from explosives at both close and long ranges. This is critical to improving the Navy's analysis of the effects of explosive sources on marine species.

About the Principal Investigator

Peter H. Dahl is a senior principal engineer in the acoustics department at the University of Washington Applied Physics Laboratory and professor in the University of Washington's Department of Mechanical Engineering. His research is in areas of acoustics with a primary focus on underwater sound. Dr. Dahl earned his Ph.D. from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution.

Key collaborators: David Dall'Osto (University of Washington Applied Physics Laboratory), Altan Turgot (Naval Research Laboratory).

MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance

Principal Investigator: Cormac Booth
Project Status: Completed, Project 43

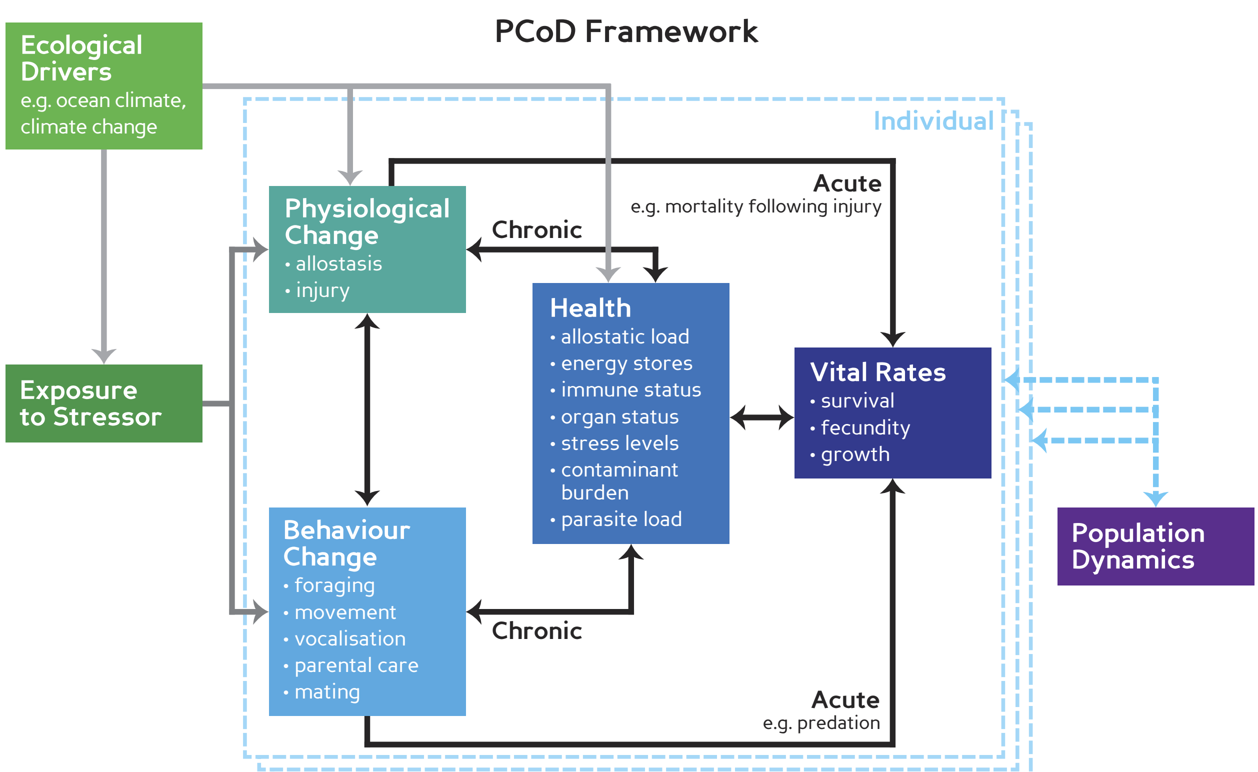
NEED

N-0207-19: Identification of Monitoring Priorities for Studying the Population Consequences of Disturbance on Marine Mammals

The population consequences of disturbance (PCoD) framework provides a conceptual framework which can be used to forecast a plausible range of outcomes for the possible effects of Navy activities on marine mammals. However, significant data gaps exist and it may take decades to fill these gaps. There is interest in identifying current methods for monitoring populations subject to disturbance that may also provide insights into the processes through which disturbance may affect these populations. The Navy is interested in a study that will inform the Navy Marine Species Monitoring program in terms of the methods and approaches that will enable the future ability to conduct PCoD analyses.

PROJECT

The overall objective of the MSM4PCoD project was to review the U.S. Navy Marine Species Monitoring (MSM) program to date and identify how current monitoring efforts could be adapted to supply appropriate data for future analyses of the consequences on marine mammals from possible disturbance by Navy activities. A working group supported by the Office of Naval Research Marine Mammals and Biology (ONR MMB) previously developed a mathematical framework for assessing PCoD. However, the PCoD framework requires a specific set of input data. It is critical to identify the data gaps that need to be filled to improve such models. Additionally, the project aimed to estimate the power of current monitoring efforts to detect changes in population size and improve methods for



Cuvier's beaked whales.
Adam U, permit 15330

detecting early warning signs of change. This project assessed how well current Navy MSM program efforts can support PCoD analyses and, filtered by feasibility of methods, recommended what could be improved.

This project assessed how well current Navy MSM program efforts can support PCoD analyses.

There were three core steps in the project's plan:

1. **Review applicable current and historical MSM projects and methodologies for priority areas and species and compile information into a reference database.**

   This included assessing the monitoring that has been conducted over the past 20 years of the MSM effort. For each monitoring study, the team documented the methods employed, the species sampled and the sample sizes obtained for different species/method combinations. The elements of monitoring determined to be relevant for PCoD were compiled into a database.

2. **Select suitable metrics for monitoring populations of deep diving odontocetes and large baleen whales using PCoD models that already exist or are currently in development.**

   The results of the first step were used to identify appropriate metrics or population characteristics that may be suitable for monitoring and that could support PCoD analyses. The modeling outputs developed (and conclusions drawn) from previous PCoD-related projects helped to define the most appropriate metrics for the power analyses planned in the third step.

3. **Conduct power analyses to assess the power of these metrics to inform PCoD analyses when collected within existing MSM projects, and determine the effort required to increase this power.**

   Power analyses ensure sample sizes are sufficiently large to allow an effect, such as changes in population size and demographics, to be detected. Conducting power analyses on information from the monitoring program helped inform whether MSM efforts to date could support PCoD analyses and identified what efforts would be required for different species/method/metric combinations.

Power depends on effect size (in this case magnitude of the long-term decline or sudden decrease) and so an important early task was to develop a range of scenarios for what determines a biologically meaningful change. After the initial power analyses, a set of simulation scenarios were developed to determine the amount and type of sampling effort that would be required for different approaches to inform PCoD in the future.

In 2020, the project team held meetings with Navy stakeholders to review monitoring objectives and efforts to date and to discuss and potentially refine the scope of the project. During review meetings and a scoping workshop, participants worked to focus the scope of the project and agree on next steps to ensure the project would support Navy needs. Parameters discussed included geographic regions for Navy monitoring and species within regions that were priorities.

Databases of Atlantic and Pacific monitoring studies were largely completed in 2021. Each data spreadsheet contained a tab for each data type and included data columns specific to the data collection method. For example, acoustic data collection details included type of passive acoustic monitoring (PAM) device, number of detections and recording hours. For Tasks 2 and 3, the project team selected metrics, using bioenergetic models for relevant species, and developed an analytical framework for determining how best to combine multiple data streams into improved power analyses. After completing the spreadsheets, the team prepared a series of case studies for Cuvier's beaked whale, one of the best monitored species. These case studies summarized the different data streams collected in the Southern California (SOCAL), Hawaii and Hatteras regions. The team then decided to focus efforts on this species in the SOCAL region.

During 2022, much of the year's work focused on testing and refining selected metrics, testing and refining models, and completing retrospective power analysis for visual and PAM surveys. Work on future power analyses (identifying what data are needed from future monitoring) also was initiated, including developing an Integrated Population Model (IPM) for SOCAL Cuvier's beaked whales.

This project suggests that the MSM program is well positioned to apply simulation case studies to predict power of a monitoring program to detect a change.

In 2023, the Atlantic and Pacific databases were updated to capture the latest estimates of the effort conducted in these testing and training areas. The team finalized databases (see References, Publications and Products list) and assessed the levels of effort carried out between regions, species and different survey methods.

For Tasks 2 and 3, Cuvier's beaked whales in SOCAL were chosen as a case study. To identify metrics of population change, the team adapted the Cuvier's beaked whale energetic population model (Hin et al. 2023) to analyze how animals might respond in a bioenergetic sense under varying environmental conditions.

Within the modeling context, they sought to identify the early warning signs of population

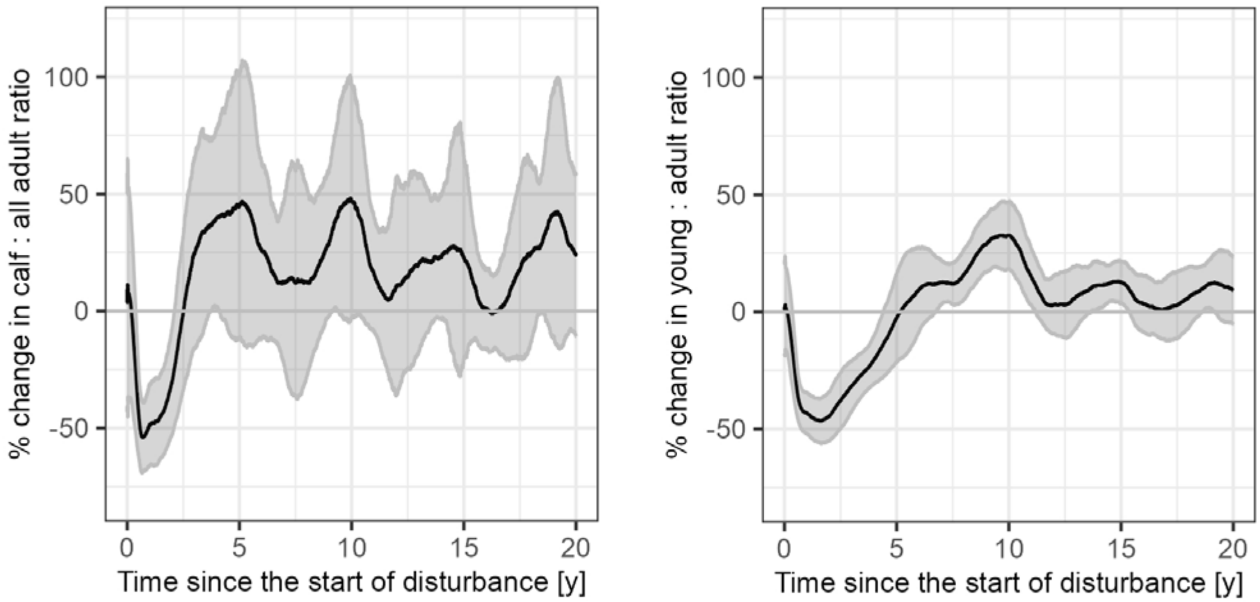


Figure 1: The early warning signs of disturbance. Changes in vital rates as disturbance starts to impact the animals in a population. Metadata overview plot for Cuvier's beaked whale in the SOCAL region, based on the review of MSM effort to date.

change and considered which of the indicators could reliably be monitored using established or emerging monitoring techniques. They concluded (based on multiple model assumptions) that two ratios—calves to adults observed and immature animals to mature animals (or ratio of 'young to all animals')—were appropriate (Figure 1). The population recovery (i.e., how long a difference in these metrics can be detected) depends on assumptions about the effect of disturbance, the quality of the environment and the strength of density dependence in this ecological system.

The team then used an IPM simulation tool to investigate how data should be collected to better detect declines. This approach can combine data on demographic parameters and population indices to estimate the parameters of a single underlying population model.

The case study simulated a hypothetical metapopulation loosely based on Cuvier's beaked whales (*Ziphius cavirostris*) in Southern California, with the eventual goal of building a framework that could be adapted for species, region or scenario. Using the information collated in Task 1 for Marine Species Monitoring program's effort on Cuvier's beaked whales in the SOCAL region (and early warning signs from Task 2), a series of simulation scenarios were designed to investigate what this IPM simulation would predict by combining effort streams. These simulations highlighted that there was a significant

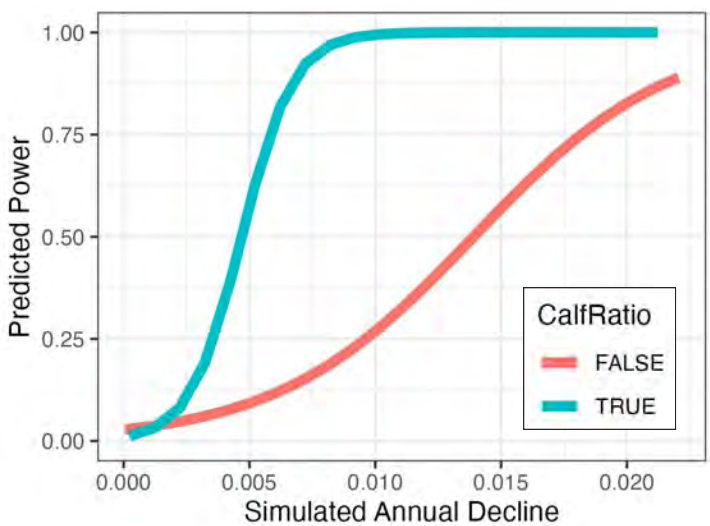


Figure 2: The importance of monitoring early warning signs demographic rates like "calf:all adult" ratio to the overall ability to detect declines.

increase in power generated from integrating datasets. In particular, including a calf:adult ratio was a key element driving the increase in power from these integrated approaches (Figure 2). The ratio was generated from photo-ID surveys in the simulation, but also could be derived from visual surveys and photogrammetry.

It's important to stress the model is a simulation. Future efforts using different declines, fitting different population models, and increasing uncertainty around parameters could help to determine the robustness of this integrated approach. This would further test the value of such approaches to the Navy in support of compliance goals.

An integrated approach looks promising for improving the power to detect changes. This is a key element of the PCoD framework and has been largely ignored to date due to challenges using classic methods. This project suggests that the MSM program is well positioned to apply simulation case studies to predict power of a monitoring program to detect a change given different survey methods, effort and sample sizes (via simulation), as well as to estimate power using empirical data (i.e. building an IPM using data collected to date).

The final report, expected in early 2024, will recommend how MSM program reporting data could be standardized, which types of studies and datasets have the highest impact on improving PCoD modeling, and which sites and methods are best candidates for monitoring.

About the Principal Investigator

Cormac Booth is Scientific Director at SMRU Consulting, University of St Andrews, UK. Dr. Booth has served as lead scientist and project manager for multiple projects involving investigating the potential impacts of marine activities on marine mammal species, including several PCoD projects. He has extensive experience in marine mammal biology, statistics and acoustics. Dr. Booth earned his Ph.D. at the University of St Andrews, UK.

Key contributors: John Harwood, Megan Ryder, Magda Chudzinska, Rachael Sinclair (SMRU Consulting, University of St Andrews, UK), Len Thomas and Eiren Jacobson (CREEM, University of St Andrews, UK), Vincent Hin (Wagenigen University & Research, Netherlands).

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Task 1 Review outputs: MSM4pCoD Atlantic and Pacific databases (including code and guidance document) https://smrumarine.app.box.com/s/u42zrd63ozmrwg55ly8aw2b8lskojs6w.

Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales

Principal Investigators:
Susan Parks, Len Thomas
Project Status: Completed, Project 44

NEED

N-0204-19: Demonstration and Validation of Passive Acoustic Monitoring (PAM)-based Density Estimation Methods Using Visually-verified Survey Data

Marine mammal density estimates are a critical input for the Navy's acoustic effects modeling. While traditional ship and aerial visual survey estimates of marine mammal density are standard methodologies for obtaining density estimates, they are very expensive to conduct, are limited in their spatial and temporal coverage and are not effective at documenting cryptic species (species that are difficult to see). The use of fixed PAM for density estimation has the potential to increase the amount of density data in all U.S. waters and Navy ranges that can be used in the Navy's acoustic effects modeling. The Navy is interested in demonstrating and validating fixed PAM-based density estimation methods using vessel or shore-based visual surveys on species that have a high confidence level in being sighted.

PROJECT

This project coupled shore-based observations with a continuous acoustic recording array to obtain acoustic cues (i.e., vocalizations) for density estimation in a Brazilian population of southern right whales (*Eubalaena australis*). This population offers a useful study opportunity because the population travels close to shore in areas with elevated hillsides suitable for concurrent fixed passive acoustic monitoring and visual observation of individuals. Previous studies with southern right whales from multiple habitats have demonstrated that the acoustic repertoires of all right whale species are similar, with the same call types described for each species. The southern right whale can thus serve as a proxy for the

Southern right whale.

highly endangered North Atlantic right whale (*Eubalaena glacialis*).

The visually verified acoustic dataset will be used to assess and validate a range of PAM density estimation methods for right whales. This approach could also improve the understanding of the sensitivity to variation in biological (age, sex, behavior), environmental (time of day, weather) and anthropogenic (ship noise) parameters.

The project's approach was to collect visual survey data concurrently with acoustic recordings of vocally active right whales using a time-synchronized fixed PAM array. Results were used to validate range-specific detection probability, false positive rates and cue (or call) rates for estimating acoustic density. Visual data were recorded from a land-based survey platform using a theodolite and a visual observation team. Whale presence can reliably be detected out to 8 kilometers (km), but the survey was focused within a 3 km radius area from the survey platform. The visual observation team detected, localized and tracked all right whale groups within that observation area.

Acoustic data were collected using underwater sound recorder units (Soundtrap 300 STD) arrayed over the 3 km radius observation area. Additional units, added outside the visual observation area, helped to determine if sounds came from outside or inside the visual detection area. For example, whales calling offshore would be detected first on the offshore unit, before detection on any of the recordings within the central array.

Additional field efforts to obtain estimates of cue rates to apply to the PAM density estimation approach included acoustic animal-borne tag (DTAG3/DTAG4) attachments on suitable weather days and focal follows and acoustic tracking of whales within the acoustic array. Density estimation was focused on two cue types (all calls and contact calls).

The effective detection area was estimated through three approaches:

1. **Spatial Capture Recapture (SCR)**
   This was the primary approach for estimating the effective detection area. It relied on detecting at least some calls on multiple underwater sound recorders.

2. **Extended SCR**
   In addition to hydrophone location, additional information such as received level and time of arrival was used to make more accurate inferences.

3. **Acoustic model-based assessment of effective detection area (EDA)**
   This was based on published values for right whale call source levels and acoustic propagation modeling. The EDA estimates were validated using visually tracked animals.

Finally, the visually obtained density estimation of right whales in the bay was compared to the output of PAM density estimates to validate the approaches applied for estimation of right whale density using passive acoustic methods.

Field efforts originally planned for 2020 were delayed due to COVID-19 pandemic restrictions. This also prevented the planned acoustic density estimations, which were to be based upon the data from the field efforts.

With continued travel restrictions in 2021, the project implemented a modified field effort. A local field team in Brazil worked with local fishermen on two deployments of a five-element acoustic array for passive acoustic data. A shore-based team collected visual data along with the acoustic data. The deployments provided approximately 1,500 hours of total acoustic data. The shore teams completed nine full days and five half days of visual data collection with shore-based theodolites, totaling almost 92 hours of

North Atlantic right whale.
NOAA

visual data. Data analyses, including synchronizing acoustic data and acoustic signal detection and hourly density counts from the visual survey, were completed.

The project team completed a full field effort in 2022. Significant amounts of acoustic and visual data were collected across the passive acoustic array, DTAG deployments and shore-based theodolite visual surveys. This includes just over 62 hours of acoustic data captured from eight DTAGs and almost 70 hours of visual data collected over six full days plus eight partial days of shore-based surveys. All tag data processing was completed, along with visual data processing from both the 2021 and 2022 surveys. Analyses of all the 2021 PAM array data and most of the 2022 array data were completed during 2022. One manuscript from the work was published in 2022 (see Publication sidebar).

Work in 2023 focused on finalizing analysis of the data collected in 2022. This included manual detection of all right whale calls on each of the acoustic recorders and tag deployments. Each of the single channel acoustic recorders were then time synchronized, and detections were assessed to determine which channels each unique call was detected on. These data were used to estimate the effective detection area for the study. Cue rates for southern right whales were estimated from the DTAGs (22 tag deployments comprising 84 hours of focal tag recordings from 14 existing tags and eight tags deployed in 2022) and visual focal follows of whales acoustically tracked inside the acoustic array in 2021 and 2022 (19 individual groups followed for seven total hours of data). Preliminary acoustic density estimations were made using spatial capture recapture methods. These values were compared to visual counts of whales present in the acoustic survey area, with a mean visual density of 1.68 animals/km2 and an acoustic density of 0.66 animals/km2.

Although some final analysis is ongoing, several important insights have been gained to inform future acoustic density estimation projects. First, the average cue rates for right whales were highly variable and dependent on the behavioral state. Improved estimates of time spent in different behavioral states by individual whales will allow more accurate cue rate estimation. These data may be easier to collect than detailed individual acoustic call rate datasets, as visual observations can be used to estimate time in behavioral states. Further, in this case, the number of sensors and spatial coverage was relatively low, meaning more data on the relative time of arrival of signals will improve the acoustic density estimation as spatial capture recapture methods are better applied to larger/longer duration survey efforts. The final analyses, including adding propagation modeling and calling whale localization for additional acoustic density estimation comparisons, will support the publications expected in 2024.

These data will inform density estimation approaches for other baleen whale species, including the endangered North Atlantic right whale.

In 2024, the visual survey data collected under the project will be contributed to the OBIS-SEAMAP online database, and tag data will be provided to the Movebank data repository. Data from this study have been shared with the ACCURATE project (Project 42, page 85) and the Cetacean Caller-ID [CETACID] project (Project 63, page 100).

The results of this validation work will allow scientists to better assess the application of different PAM density estimation approaches for right whales. These data will inform density estimation approaches for other baleen whale species, including the endangered North Atlantic right whale, by providing a better understanding of the variability in cue rates and the most appropriate methods to estimate density from PAM.

About the Principal Investigators

Susan Parks is Professor of Biology at Syracuse University in Syracuse, NY. She specializes in bioacoustics, focusing on the use of sound for communication and the impacts of noise on development, behavior, sound production and reception. Dr. Parks holds a Ph.D. in biological oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography/Applied Ocean Science.

Len Thomas is Professor of Statistics and member of the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. He specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in forestry from the University of British Columbia.

Key contributor: Graduate student Julia Dombroski (Syracuse University).

Publication

Zeh, J.M., Dombroski, J.R. and Parks, S.E. (2022). Preferred shallow-water nursery sites provide acoustic crypsis to southern right whale mother-calf pairs. *Royal Society Open Science*, 9(5):220241. DOI 10.1098/rsos.220241.

Collection of *in situ* Acoustic Data for Validation of U.S. Navy Propagation Models of Ship Shock Trial Sound Sources

Principal Investigators:
Kerri Seger, Shyam Madhusudhana
Project Status: Completed, Project 48

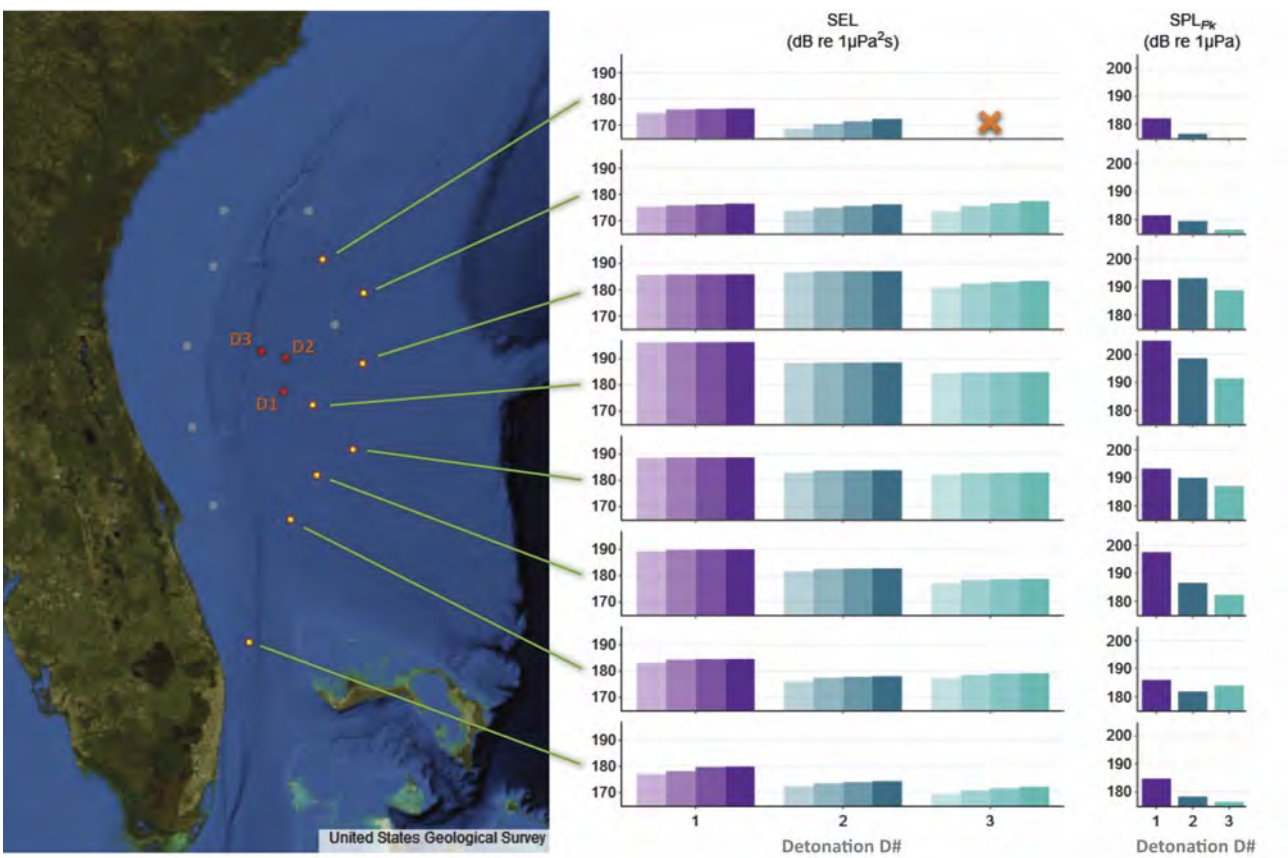
NEED

N-0226-21: Ship Shock Trial Acoustic Measurement

Each new class (or major upgrade) of surface ships constructed for the Navy undergoes an at sea shock trial. A shock trial is a series of underwater detonations at various distances from the ship, each of which sends a shock wave through the ship's hull to simulate near misses during combat. The Navy collects data on the acoustic shock waves effects on the ship and equipment and estimates the impact to the environment through acoustic models. However, few *in situ* measurements of the extent of the acoustic propagation within the marine environment have been taken. The Navy needs *in situ* data on acoustic shock wave propagation from the trials through the surrounding marine environment to enhance the Navy's predictive acoustic modeling methods.

PROJECT

The goal of this project was to collect relevant *in situ* data on the acoustic shock wave propagation from a full ship shock trial (FSST). This project began in April 2021 to support the FSST of the new Navy aircraft carrier, USS *Gerald R. Ford* (CVN-78). To capture *in situ* data, underwater acoustic recording devices were deployed at near- and far-field locations around the ship shock trial



Deployment locations of Rockhoppers, with (yellow dots) and without (light gray dots) pertinent recordings, around the three detonations (D1 through D3; red dots) from the 2021 FSST. The bar charts show corresponding measured sound exposure levels (with different integration times) and peak received levels.

zone. To determine optimal locations for the recording devices, the team analyzed physical environmental data—including water column structure, depth, wave height and wind speed, bathymetry and bottom sediment type—as well as anticipated (modeled) received level maps. All recorders were largely configured the same way at all sites to ensure that measurements could be easily standardized across devices. The deployed device settings did differ in the hydrophone sensitivities and gain control settings based on proximity to the ship shock trial location (i.e., near-field or far-field).

Recorders, including 15 moored autonomous recording devices (Rockhoppers) and six underwater acoustic recorders (SoundTraps), were deployed in June 2021 and recovered in September 2021. During the course of the FSST, three detonations occurred (June 18, July 19 and August 8). After retrieving the devices in late August 2021, the team made copies and delivered the data to the Navy for security screening. In summary, 11 of the 15 Rockhoppers recorded data successfully from all three detonations, two of the Rockhoppers only recorded the first detonation and two of the Rockhoppers did not capture any of the detonations. Of the six SoundTraps, one recorded data successfully from all three detonations, four recorded data from the first and second detonation, and one did not capture any of the detonations.

The project team received screened data in early 2022 and began analyses of acoustic shock wave propagation and estimated received levels at each of the Rockhopper recorders. As an example, Site S04 was the closest to the first detonation (approximately 35.9 km) and had a peak level (L_{peak}) of 204.84 dB re 1 µPa and sound exposure level over a 5 second period ($SEL5_s$) of 196.26 dB re 1 µPa2s. For comparison, Site S15 was the farthest from the third detonation

Rockhopper acoustic recording devices ready for a research deployment.
Shyam Madhusudhana

(approximately 328 km) and had a peak level (L_{peak}) of 176.39 dB re 1 µPa and sound exposure level over a 5 second period (SEL_{5s}) of 169.42 dB re 1 µPa2s.

Among other products, analytical results were used to estimate the source level of explosions from each deployment location and to generate impact volume maps. In addition, the team obtained Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) data from receiver HA10N, near the Ascension Islands, to calculate received levels at long distances. Most of the acoustic energy of the detonation, as received by the CTBTO hydrophones, was contained between 3–0 Hz (unlike 5–100 Hz at the Rockhopper locations).

Analytical results were used to estimate the source level of explosions from each deployment location and to generate impact volume maps.

The SoundTrap data were analyzed for the presence of biological acoustic activity such as odontocete, baleen whale and fish sounds. These data were also analyzed using the Before-After Control-Impact (BACI) methodology to estimate acoustical presence and behavior of marine species before and after detonations. Overall, there was no consistent calling activity correlation with explosions from any broad calling group. If a BACI change existed and was statistically significant, the calling activity could go either way (e.g., four with more calling activity after, three with less calling activity after). However, if counting any qualitative BACI change that was not statistically significant, the calling activity tended to decrease after the explosions.

The team completed data analyses during 2023 and provided a final report. These *in situ* data of received levels and spectra were provided to NAEMO modelers to validate the NAEMO acoustic propagation model with ship shock trial explosive sources. The data will ensure that the Navy's estimates of acoustic impacts from explosive sources are as accurate as possible.

About the Principal Investigators

Kerri Seger is a senior scientist at Applied Ocean Sciences. She is also an affiliate research professor with the Center for Acoustics Research and Education at the University of New Hampshire. Her areas of expertise include soundscape parameterization, propagation modeling, bioacoustics and field design. Dr. Seger earned her Ph.D. in oceanography (specialty in bioacoustics) from Scripps Institution of Oceanography.

Shyam Madhusudhana began this project as a postdoctoral research associate at the K. Lisa Yang Center for Conservation Bioacoustics, Cornell Lab of Ornithology, Cornell University, under the supervision of Dr. Holger Klinck. He is now a research fellow at the Centre for Marine Science & Technology, Curtin Mauritius. His areas of expertise include passive acoustics, automatic pattern recognition and signal processing. Dr. Madhusudhana earned his Ph.D. in applied physics at Curtin University, Australia.

Key contributors: Holger Klinck (Cornell University), Kevin Heaney and Christopher Verlinden (Applied Ocean Sciences).

Studying Marine Mammal Behavioral Response to SURTASS LFA Sonar Phase I

Principal Investigators: Multiple (see text)
Project Status: Completed, Projects 52, 53, 54

NEED

N-0240-21: Studying Marine Mammal Behavioral Response to SURTASS LFA Sonar

The Navy plans to continue to train and test with the Surveillance Towed Array Sensor System (SURTASS) Low Frequency Active (LFA) sonar systems in the western and central North Pacific and eastern Indian oceans. Because acoustic stimuli from SURTASS LFA sonar use during training and testing has the potential to cause harassment of marine mammals, additional study and new data on these potential effects are needed. Understanding behavioral response to the LFA source is a priority.

PROJECT

The goal of the overall SURTASS effort is to update previous studies done with LFA sources during the 1990s, based on lessons learned and best practices from controlled and observational behavioral response studies using other sonar sources conducted over the last 10 years. The Navy will evaluate the feasibility and appropriate methods to collect new data to supplement the data available on behavioral responses of marine mammals to SURTASS LFA sonar using newer methods and technologies.

The effort is following a two-phase approach. The completed Phase I, initiated in 2021, was a feasibility study to investigate the best approach to designing a scientific study to assess behavioral response to LFA sonar. This involved discussions with the program managers regarding Navy participation, appropriate LFA sound sources and final plan design. Phase II will be based on results of Phase I.

> The results of the Phase II effort will provide the Navy with important and current data needed to meet environmental compliance for using SURTASS LFA.

The following three projects were awarded under Phase I:

- Project 52—Low Frequency Active Sonar Scientific Research Project 4 Feasibility Study (Adam Frankel, Marine Acoustics, Inc.).
- Project 53—Approaches for Examining Behavioral Responses of Whales to SURTASS Low Frequency Active Sonar (John Calambokidis, Cascadia Research Collective/Brandon Southall, Southall Environmental Assoc.).

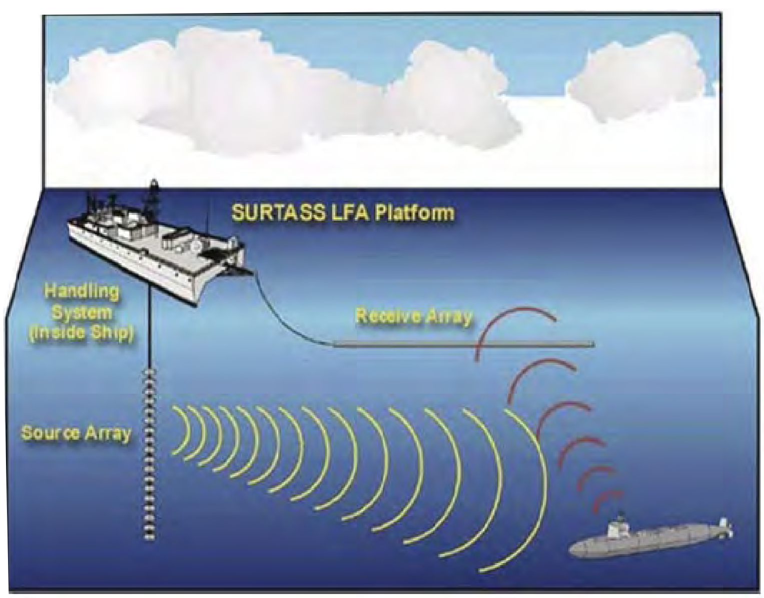


Diagram showing operation of a Navy SURTASS LFA platform at sea.

The ocean surveillance ship USNS *Able* (T-AGOS 20).
MC2 Brian G. Reynolds

- Project 54—Simple and Understated: Risk Team Assessment of Low-Frequency Active Sonar (SURTASS LFA) (Stephanie Watwood, Naval Undersea Warfare Center/Greg Schorr, Marine Ecology and Telemetry Research).

During 2022, each project team presented its status, responded to questions from the LMR Advisory Committee and asked clarifying questions during closed sessions at the 2022 LMR In-progress Review. All final reports detailing each team's recommendations, the remaining product of Phase I, were completed in 2023.

During 2023, LMR program managers worked with the Maritime Surveillance Systems Program Office (PMS 485) to determine the availability of a sound source to support the project during Phase II. It was determined that the preference is to use a single element of the SURTASS LFA array as the sound source. However, that requires an 18-month development period to get it ready to use in the field. Consequently, Phase II is unlikely to begin before 2026.

The Phase II project will be a separately funded effort. Phase I awardees will need to compete for a Phase II award. The anticipated Phase II period of performance will be based on proposed study design requirements, not to exceed five years.

The results of the Phase II effort will provide the Navy with important and current data needed to meet environmental compliance for using SURTASS LFA during training and testing activities. The data will be provided to the Navy and will support the at-sea environmental compliance community in environmental criteria development.

Dolphin Conditioned Hearing Attenuation

Principal Investigator: Jim Finneran
Project Status: Completed, Project 55

NEED

N-0225-20: Marine Mammal Conditioned Attenuation of Hearing Sensitivity

Multiple studies with several marine mammal species have demonstrated conditioned reductions in hearing sensitivity. These results raise more questions about the mechanisms marine mammals use to reduce their hearing sensitivity and implications for marine mammal hearing. The Navy needs better understanding of the extent of control marine mammals may have over reducing their hearing sensitivity, what anatomical and physiological mechanisms they may be using, and the impact on temporary threshold shift (TTS) response. An investigation into any additional species available in captivity is needed.

PROJECT

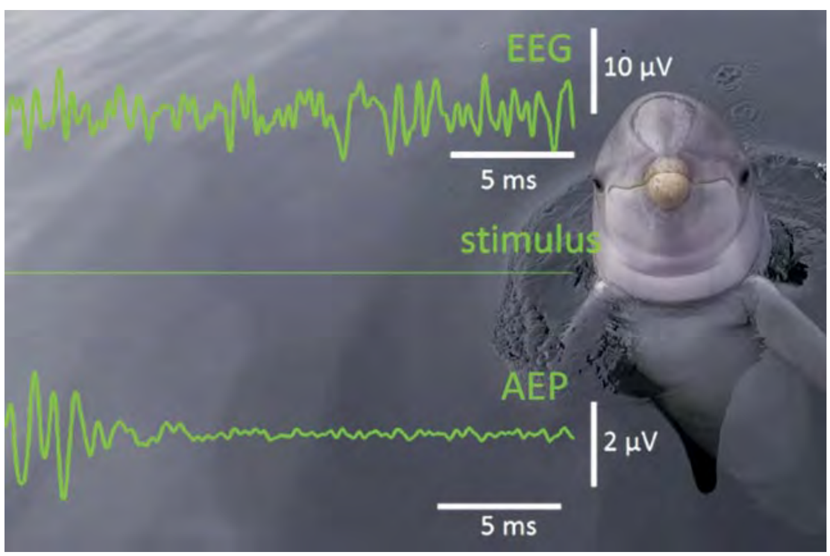
This project was focused on three primary objectives:

1. Measure how quickly dolphins can learn to suppress (i.e., attenuate) their hearing in anticipation of an impending intense sound.
2. Determine how long they can maintain the attenuation.
3. Assess the role of outer hair cells in the conditioned hearing change.

Understanding both the extent to which dolphins can voluntarily manipulate their hearing sensitivity and the underlying mechanisms is required to properly evaluate laboratory data relating hearing loss to noise exposures.

This work was co-funded by the LMR program and the Naval Information Warfare Center (NIWC) Pacific Naval Innovative Science and Engineering (NISE) program. The project team assessed conditioned hearing attenuation in bottlenose dolphins by measuring changes in auditory evoked potentials (AEPs)—small voltages generated by the brain and auditory nervous system in response to sound—when dolphins are warned of an impending intense sound. The team worked with bottlenose dolphins from the United States Navy Marine Mammal Program that are trained for participation in AEP studies.

During each experimental trial, AEPs generated by a continuous sequence of tone bursts were tracked first before a warning sound, then after the warning sound but before an intense sound and, finally, after the intense sound. Conditioned hearing changes were revealed by decreases in AEP amplitude and increases in AEP latency occurring after the warning sound, but before the intense sound. This temporal separation eliminates the possibility that AEP attenuation is a result of auditory masking or noise-induced hearing loss (i.e., caused directly by the intense



A bottlenose dolphin with examples of the instantaneous EEG and AEP in response to a tone burst stimulus.


Bottlenose dolphin.
NOAA

sound). Across experimental sessions, features of the AEP stimulus, the warning sound and the intense sound were manipulated to reveal temporal and spectral characteristics of the conditioned hearing attenuation phenomenon.

Measurements of AEPs in the presence of on- and off-frequency masking noise were made to identify an AEP correlate for proper outer hair cell function. These AEP measurements were conducted during periods of conditioned hearing attenuation to try to determine if the attenuation was mediated by changes to outer hair cells/cochlear amplifier gain.

The project began in late 2021 with work to refine testing procedures, conduct baseline testing and determine whether dolphins would attenuate their hearing during repetitive noise exposures occurring at a fixed rate with increasing sound pressure level (SPL), but without an otherwise explicit warning. These efforts were completed in 2022 and the results published in early 2023. AEP measurements were also conducted with seven dolphins to look for correlations between AEP measurements and outer hair cell function. These data were collected in 2022 and analyzed in 2023. Although an AEP correlate for outer hair cell function could not be established, the methods and results were documented in a 2023 NIWC Pacific Technical Report.

Also during 2023, archival data collected in 2013 during measurements of temporary threshold shift (TTS) in dolphins exposed to sequences of impulses were analyzed. The results showed clear AEP attenuation before each impulse and rapid increase in AEP amplitude just afterwards, and spectral analysis revealed a dominant peak matching the rate of the air gun exposures (part of the 2013 dataset). Similar temporal/spectral correlation with the simulated impulses was not seen in the control data. The data add further evidence that dolphins can learn the timing of repetitive sounds presented at intervals up to at least 10 to 20 seconds and may reduce their hearing sensitivity when they anticipate the next exposure in the sequence, even without an explicit warning. These results were published in the *Journal* *of the Acoustical Society of America* in 2023 (See Publications sidebar).

The main data collection in 2023 consisted of two experiments. In the first, AEPs were continuously measured in two dolphins as they were exposed to first a warning sound, then a more intense sound. The duration of the intense sound was varied from 0.5 to 16 seconds. AEPs in one dolphin showed the expected conditioned hearing attenuation after the warning and before the intense sound. However, the second dolphin showed no AEP attenuation before the intense sound, but instead short-term auditory fatigue and recovery following the exposure. These data represent the first measurement of auditory fatigue in a marine mammal at such short time scales (a few seconds compared to typical TTS measurements occurring several minutes after exposure). The results of this experiment were submitted for publication in November 2023.

The results of this project improve our understanding of the circumstances under which marine mammals are likely to attenuate their hearing.

In the second experiment, a dolphin was trained to attenuate his hearing upon detecting a warning sound and maintain the attenuation until the warning sound ceased and a more intense sound occurred. Over several weeks the duration of the warning was randomized and the upper limit gradually increased. Using this approach, conditioned attenuation was observed for up to 43 seconds.

The results of this project improve our understanding of the circumstances under which marine mammals are likely to attenuate their hearing, and the potential impacts of conditioned hearing attenuation on laboratory TTS data and current acoustic criteria. The data will support developing accurate acoustic criteria and ensure compliance with environmental laws.

About the Principal Investigator

James Finneran has worked as a research scientist at the NIWC Pacific since 2002, investigating marine mammal echolocation and marine animal auditory capabilities and studying the physiological effects of sound on marine animals. Dr. Finneran earned his Ph.D. in mechanical engineering from The Ohio State University.

Publications

Finneran, J.J., Lally, K., Strahan, M.G., Donohoe, K., Mulsow, J. and Houser, D.S. (2023). Dolphin conditioned hearing attenuation in response to repetitive tones with increasing level. *The Journal of the Acoustical Society of America*, 153(1):496-504. DOI 10.1121/10.0016868.

Finneran, J.J., Schlundt, C.E., Bowman, V. and Jenkins, K. (2023). Dolphins reduce hearing sensitivity in anticipation of repetitive impulsive noise exposures. *The Journal of the Acoustical Society of America*, 153(6):3372-3377. DOI 10.1121/10.0019751.

Finneran, J.J., Strahan, M.G., Mulsow, J., Houser, D.S. and Burkard, R.F. (2023). "Investigating auditory brainstem response correlates of basilar membrane nonlinearities in dolphins," NIWC Pacific TR-3312 (Naval Information Warfare Center (NIWC) Pacific, San Diego, CA).

Bryde's Whale Cue Rates and Kinematics

Principal Investigator: Tyler Helble
Project Status: Completed, Project 58

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 modified existing passive acoustic monitoring (PAM) tools, previously developed at Naval Information Warfare Center (NIWC) Pacific, to acoustically detect, localize, classify and track Bryde's whales (*Balaenoptera brydei*) on the Pacific Missile Range Facility (PMRF). The results also are helping to determine animal cue rate (calling rate) and stability, necessary for acoustic density estimation.

The project team updated and applied detection/localization software code to long-term recordings (from 2011–2022) from PMRF to obtain 150 acoustically derived Bryde's whale tracks. After manually validating tracks to include any missed calls and eliminate false localizations, they adapted existing code, including continuous-time random walk (CRAWL) model and Hidden Markov models (HMMs), to analyze Bryde's whale cue rates and swimming behavior (kinematics).

In 2022 the project team began updating and adapting the existing detection and localization code to obtain Bryde's whale raw tracks and adding relevant variables needed for manual validation. The team identified and validated 101 Bryde's whale tracks from 2012-2017 data and began manual track validation in the Raven-X software package. (See also Project 62, Raven-X:

Bryde's whale.
Adam U, NOAA

Bryde's whale.
Wayne Hoggard, NOAA

Enhancing the Efficiency of Large-scale Bio-acoustic Analyses, page 95.)

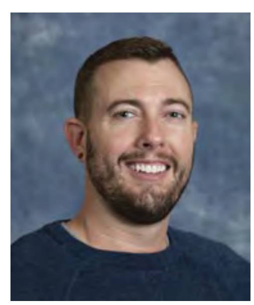
Work in 2023 focused on additional manual track validation work, finishing code adaptions to apply to Bryde's whale tracks and analyzing the data for trends and behavior attributable to conspecifics (other Bryde's whales near a focal animal).

This research is the first to shed light on seasonal Bryde's whale movement in the central North Pacific.

The team identified seasonal and day/night (diel) patterns of movement and calls. Tracks were organized into three seasonal groups with most tracks falling within one season and showing a distinct directional heading. Bryde's whales swam faster in the daytime and slower at night. Applying a labor-intensive process to analyze and manually add missed calls, the team was able to obtain accurate inter-click intervals (ICI) and call types. There is some indication that the median ICI is lengthening over time for Bryde's whales. The results may offer insights into population groupings around Pacific regions and will contribute to cue rates needed for density estimation. A manuscript with details of the analyses and results, Swim Kinematics and Acoustic Calling Behavior Attributed to Bryde's whales in the Central North Pacific, is in review for publication in Frontiers in Marine Science.

This research resulted in new acoustic capabilities and is the first to shed light on seasonal Bryde's whale movement in the central North Pacific. With little previous movement data, the swimming behavior of Bryde's whales has been poorly understood, and this information could inform models such as ship-strike risk and sonar exposure models. The adapted and tested tools also expand the Navy's ability to automatically track and measure kinematics of key species on PMRF.

About the Principal Investigator



Tyler Helble is a bioacoustics scientist and electrical engineer at the Naval Information Warfare Systems Center, Pacific. Dr. Helble earned his Applied Ocean Science Ph.D. at the University of California San Diego. His main area of focus is developing tools for detection, classification, localization and density estimation of cetaceans using passive acoustics.

Auditory Masking in Odobenid and Otariid Carnivores

Principal Investigators:
Colleen Reichmuth, Jillian Sills
Project Status: Completed, Project 61

NEED

N-0136-17: 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 collected auditory data for odobenid and otariid carnivores (Pacific walruses and California sea lions, respectively) that will enable comparison of acoustic sensitivity between these marine mammal taxa and support environmental compliance efforts. The LMR program funding for this project supplemented an ongoing effort supported by the U.S. Fish and Wildlife Service in partnership with the U.S. Geological Survey to characterize auditory masking in the Pacific walrus (*Odobenus rosmarus divergens*). The added support from LMR enabled the project team to expand the study scope to include a California sea lion (*Zalophus californianus*) and collect additional comparative data.

The project team worked with two Pacific walruses trained for voluntary participation in behavioral audiometric testing and one California sea lion with previous experience in this type of work. Ambient hearing thresholds were collected in outdoor conditions; background noise was

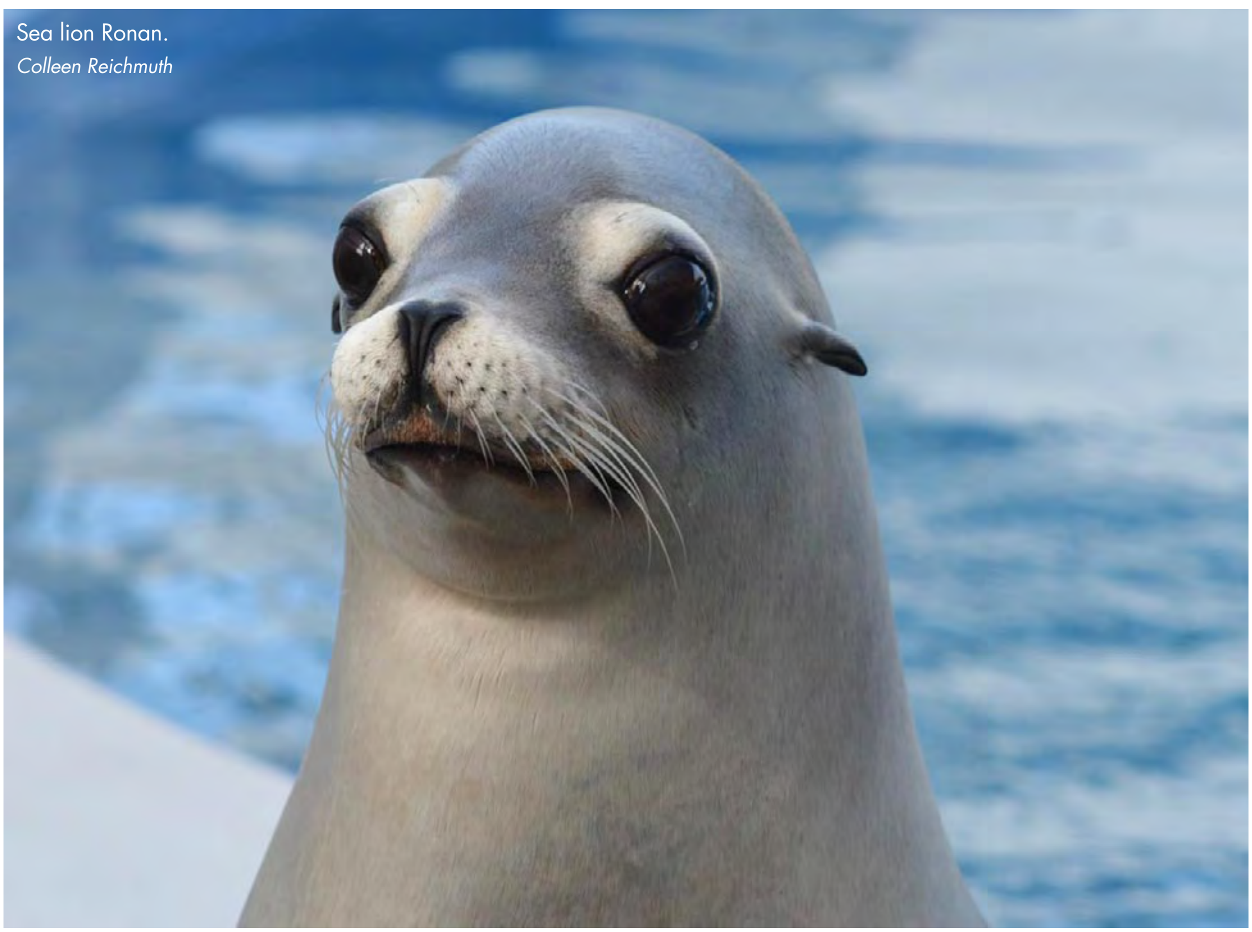
Pacific walrus.
Tyrone Donnelly, USGS

characterized in the testing environment to allow measured thresholds to be evaluated. Masked hearing thresholds were then collected in the presence of spectrally flattened, spatially mapped octave-band noise set at or above the sound pressure level of the ambient hearing threshold. Based on these measurements, auditory critical ratios were calculated for each frequency. These ratios were used to evaluate the ambient hearing measurements obtained in natural noise, to determine which threshold measurements were influenced by the surrounding environmental conditions. Importantly, the critical ratios measured in this study can be used to predict masking across a broad frequency range due to the presence of noise in both terrestrial and marine environments.

Data collection was completed during 2022. The ambient and masked low-frequency hearing thresholds with both species extended the frequency range evaluated in this study from 80 Hz to at least 16 kHz. The sea lion data also served as validation for the outdoor testing method because this individual's hearing was previously measured at the same frequencies in a controlled acoustic environment.

The critical ratios measured in this study can be used to predict masking across a broad frequency range.

During 2023 the team completed data analyses and a study publication (see Publication sidebar).



Sea lion Ronan.
Colleen Reichmuth

This project's results reveal that in terms of absolute hearing ability, walruses are more sensitive than sea lions at lower frequencies and less sensitive at higher frequencies. However, despite differences in their hearing profiles, odobenid and otariid carnivores are similarly able to detect signals in noisy conditions. This unusual method of estimating masking parameters in outdoor conditions—validated through testing of human and sea lion subjects—can be applied to species that cannot be tested in ideal conditions.

The results provide new information relevant to noise exposure criteria for one of the least studied marine mammal functional hearing groups.

This effort bolsters resources for Navy's at-sea environmental compliance and permitting processes, especially in the Northwest and Arctic regions of the North Pacific, essential to U.S. Navy operations. The results provide new information relevant to noise exposure criteria for one of the least studied marine mammal functional hearing groups, "Other Marine Carnivores." This is a grouping of amphibious marine mammals that are not phocids (true seals), and includes sea lions, fur seals, walruses and sea otters.

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 Institute of Marine Sciences, University of California Santa Cruz. She is a skilled bioacoustican 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 student Ryan Jones (University of California Santa Cruz), Rob Williams (Oceans Initiative), Jason Mulsow (National Marine Mammal Foundation)

Publication

Jones, R., Sills, J.M., Synott, M., Mulsow, J.M., Williams, R. and Reichmuth, C. (2023). Auditory masking in odobenid and otariid carnivores. *Journal of the Acoustical Society of America*, 154(3):1746-1756. DOI 10.1121/10.0020911.

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 the Navy's environmental compliance and permitting process, 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 eight ongoing projects and two new start projects.

The ongoing projects are

1. Project 32—Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals
2. Project 37—Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales (SOST)
3. Project 38—Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds (SOST)
4. Project 40—Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles
5. Project 45—Frequency-dependent Underwater TTS in California Sea Lions
6. Project 47—Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds
7. Project 50—Loudness Perception in Killer Whales (*Orcinus orca*); Effects of Temporal and Frequency Summation
8. Project 51—Dependence of TTS on Exposure Duration During Simulated Continuous Active Sonar: Examining the Equal-energy Hypothesis for Long-duration Exposures

The new start projects are

1. Project 64—3S4–Effect of Continuous Active Sonar and Longer Duration Sonar Exposures
2. Project 67—Measuring behavioral responses of Cuvier's beaked whales to continuous active sonar in the Atlantic.

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 previ-

Monk seal KP2.
Colleen Reichmuth, permit 24054

ously 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.

This project addresses the most pressing knowledge gaps concerning auditory biology for Hawaiian monk seals.

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 will be 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 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 support an underwater audiogram. They also maintained an autonomous acoustic recorder within KP2's pool, successfully collecting a full

Monk seal KE18 and trainer Traci Kendall participate in auditory measurements in the specialized testing facilities at Long Marine Laboratory.
Colleen Reichmuth, permit 19590

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/.

The results of this effort provide a comprehensive understanding of hearing in endangered Hawaiian monk seals.

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 environment—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. Manuscript preparation is underway, with expected submission in 2024. The timing of KP2's return to the Waikiki Aquarium will be determined in coordination with the project partners at Waikiki Aquarium and NMFS but is expected during 2024 or 2025.

The results of this effort provide a comprehensive understanding of hearing in endangered Hawaiian monk seals and 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 and University of Hawaii) and Brandi Rusher (University of California Santa Cruz), monk seal specialists Traci Kendall and Beau Richter (University of California Santa Cruz). The National Marine Fisheries Service and Sea Life Park Hawaii helped to facilitate this research program.

Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales

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

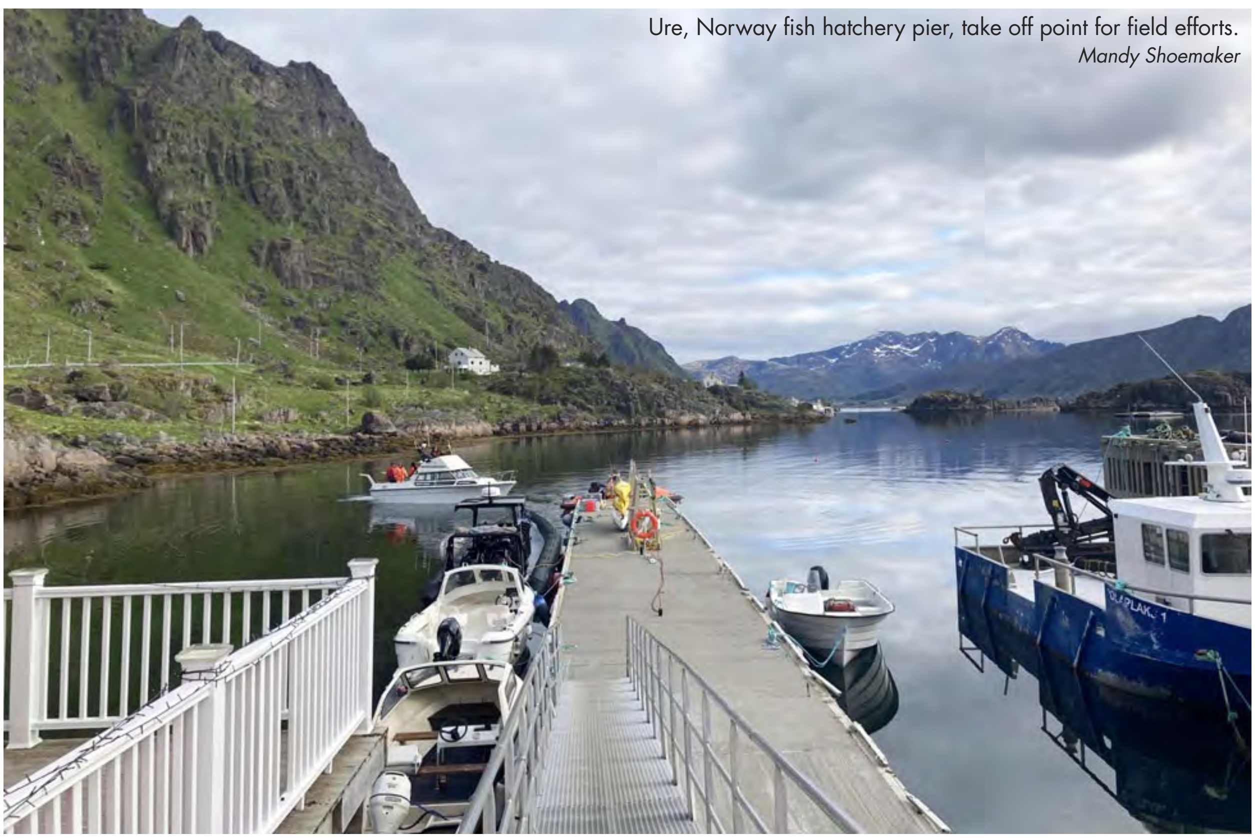
NEED

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 126, for more information), is focused on obtaining *in situ* auditory evoked potential (AEP) measurements of the hearing sensitivity of mysticetes. 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 project team plans to obtain AEP hearing thresholds for minke whales (*Balaenoptera acutorostrata*), which will



Ure, Norway fish hatchery pier, take off point for field efforts.
Mandy Shoemaker

provide the first direct measurement of hearing in a mysticete (baleen whales).

The project team is working to measure the hearing of minke whales temporarily confined in a fjord off the Norwegian coast. They will use AEP methods specifically modified for these animals. The research focuses on small (3–5 meters long) juvenile minke whales because they are more suitable for handling, should have good hearing capabilities and the chance of success with the AEP methods increase (because of their smaller size). Juvenile minke whales are similar in size to wild beluga whales that have been temporarily caught and released for AEP testing.

Researchers will use both broadband and narrow-band acoustic stimuli to collect frequency-specific hearing thresholds needed for a minke whale audiogram.

Modifications to AEP methods will largely consist of adapting approaches previously worked out on smaller cetaceans with a special focus on sound delivery and AEP recording at lower frequencies. When testing, researchers will use both broadband and narrow-band acoustic stimuli to optimize procedures and collect frequency-specific hearing thresholds needed for a minke whale audiogram. Each whale will be 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 requires 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. The guide net system was modified so that the eastern guide net was attached to a small island, thus eliminating one route by which a whale could leave the catch system after entering.

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 is 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.

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

The project team will return to Norway for a final season in 2024 with the hopes of completing the first-ever mysticete audiogram.

Corralling phase.
Rolf Arne Ølberg


Minke whale in the hammock.
Eric Franks

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

Additionally, if low-frequency thresholds can be obtained, they will provide information needed to develop auditory weighting functions for mysticetes, which currently lack empirical data on which to base the functions. Techniques developed during the minke whale hearing tests also will facilitate future audiometric measurements on other mysticete species. Audiometric data and methods developed for testing of mysticete hearing will be described in peer-reviewed publications.

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 environmental 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).

Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds

Principal Investigators:
Rebecca Dunlop, Michael Noad
Project Status: Ongoing, 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 126, for more information), is addressing the portion of the need related to using behavioral response methods to test the hearing sensitivities of large whales. The project team is 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 will be a proxy for audiometric measurements to estimate hearing sensitivity in baleen whales.

The project team is conducting a series of field experiments in a unique site near Queensland, Australia. The team's field plan includes both a team of land-based visual observers, who record 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 attach motion and sound


Humpback whale.

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

recording tags to some of the whales to record fine-scale changes in movement and dive behavior as well as their acoustic environment.

Another on-water team deploys a sound source from a vessel, playing upsweep tones at various frequencies to approaching whales. The source level of the tone remains constant throughout the experiment. The experiments follow a 'before/during' protocol, where the target whale group behavior is continually recorded 'before' and 'during' the tone playback. The playback begins when the whales are too far from the source to hear it (based on assumptions about their hearing in noise). As the whales approach the sound source, the received level of the tones at the focal group will increase until, at some point, the tones become audible to the whales. At this point, the focal group usually changes behavior by temporarily stopping, changing direction to avoid the vessel and/or changing dive behavior. The received level is measured at the point at which they change behavior to give an indication of detection-and-response threshold of the signal in noise. This is repeated multiple times for each frequency, using different groups of whales. Experiments in which the vessel is present, but no tones are transmitted, are also conducted to provide a control sample. This will help quantify the behavioral response, as well as make sure the response is to the tone stimulus and not the presence of the vessel.

A four-phase experimental routine is 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 signal is detected and the group responds by avoiding the acoustic source/vessel.
4. After phase—Conduct additional *in situ* acoustic measurements and recover tag.

The study site provides several benefits: lower noise levels than many ocean sites; an extensively measured and characterized acoustic environment; and a wealth of background data on whale movements, normal behaviors and abundance based on 11 previous field seasons. These benefits support tagging efforts and facilitate 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 needed to revise 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.

The 2021 field season was also affected by pandemic travel restrictions, which reduced volunteer staffing for the land-based observers by approximately one-third. Results of the test runs in 2020, however, 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

Land-based observation team on Emu Mountain with an observer using binoculars, an S2SS operator, and a theodolite operator.
The Cetacean Ecology Group, University of Queensland

(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 is effective at eliciting a response that indicates a sound is being heard.

In 2023, the team conducted their final round of field trials. A total of 32 sound trials and eight control trials were completed, with seven Acousounde tags successfully deployed and retrieved. Frequencies tested were 60 Hz, 250 Hz, 1 kHz, 4 kHz, 16 kHz and 22 kHz sweeps.

> The resulting information on humpback whale hearing will help to model the potential effects of noise-producing activities on humpback whales.

Overall, the total number of completed sound exposure experiments was 82 with tagged animals in 11 of those experiments. This total includes 12 control experiments. Data analysis is underway, but results show that whales are consistently responding to all tested frequencies (60 Hz to 22 kHz). For each frequency, the lowest received level, and lowest received signal-to-noise ratio measured at the behavioral change-point, will be used to infer the hearing sensitivity of humpback whales in natural noise. A final project report is expected by the end of 2024.

The resulting information on humpback whale hearing, including data on how well humpback whales can hear under ambient 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, will help to validate and integrate the modeling approach with real data, and will 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.

Publications

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: Ongoing, 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 is examining auditory TTS in two species of freshwater aquatic turtles and will potentially provide the cumulative sound exposure levels and durations that induce TTS in these species. The work also will include examining the turtles' ear anatomy to support physiological comparisons between freshwater and marine turtle hearing apparatus. This will help to identify potential TTS susceptibility of sea turtles based on freshwater turtle data. Results will provide researchers, managers and stakeholders critical data to improve estimates of acoustic effects to both freshwater and sea turtles. Results also will inform the development of appropriate mitigation measures to reduce potential effects to sea turtles from low-frequency anthropogenic sound. This project is co-funded by the LMR program and NOAA.

Initial underwater hearing measurements and TTS assessments are being conducted with two freshwater turtle species—the eastern painted turtle (*Chrysemys picta picta*) and red-eared slider (*Trachemys scripta elegans*). Physiological auditory evoked potential (AEP) methodology is being applied. Testing two species increases sample sizes, which supports both developing robust TTS measurement supported by multi-species comparisons and identifying if there are methodological challenges/differences between species. Additionally, comparing TTS onset and growth in the two surrogate taxa contributes to understanding potential TTS variability between turtle species. Examining for potential TTS in multiple animals allows for additional measurements of variability. Initial AEP measurements of hearing sensitivity are being followed by sound exposure trials and anatomical imaging as summarized below.

- **AEP testing**

  Baseline hearing sensitivity is measured by recording AEPs, a rapid, non-invasive technique that is used to measure hearing in a diverse array of taxa including fishes, squid, seabirds, odontocetes, manatees, pinnipeds, sharks and sea turtles.

  Initial hearing thresholds to determine a baseline audiogram are measured at a variety of frequencies between 50 and 5,000 Hz (with additional frequencies added as needed). This method is well established and encompasses the full anticipated range of turtle hearing. At each frequency, sound levels are decreased until AEP responses can no longer be detected (threshold).

- **Sound exposure trials**

  Sound exposure trials explore the durations and sound pressure levels (SPLs) required to induce TTS onset and develop an empirically based predictive curve of TTS onset. The trials expose turtles to broadband white noise that spans their auditory frequency range and is likely to cause TTS. Fatiguing noise SPLs start at lower levels and increase or decrease as needed to induce TTS (up to certain SPLs) in a semi-random manner; similarly, durations are increased or decreased to achieve targeted overall sound exposure levels (SELs) and a range of TTS amounts. These data are being used to define the hearing sensitivity curve of both species.

- **Anatomy**

  The project is also examining the similarities and potential differences of the auditory anatomy of control animals and those exposed to sound to identify potential short- and long-term anatomical effects of TTS. Auditory hair-cell damage and loss in some marine taxa have served as indicators of sound exposure and these indicators could apply to turtles. Defining methods by which to assess damage would support examining other turtle species in the future.

Multiple methods are being explored as options. The first involves using x-ray computed microtomography (μCT or standard CT) to examine morphology on the micro-scale. Although μCT on turtle ears has not been previously conducted and using these methods to gauge hair cell health and status may be challenging, it offers a good, non-invasive first step. Second, researchers may seek to image auditory hair cells using fluorescent immunohistochemical procedures (which provide

Red-eared slider.
Andria Salas


Loggerhead sea turtle.

high-resolution imaging at a cellular level) and other readily available methods used in an array of animals, from fish to invertebrates and mammals. The third imaging option is scanning electron microscopy. The latter two are fatal to the turtles, thus researchers are focusing on the minimally invasive CT work.

Based on the results of these efforts, the team will explore dose-dependent effects to begin to create a noise-based, dose-dependent model of TTS. This will allow regulators and data users to predict the sound levels and durations that may produce TTS onset in turtle species. Project products also will outline the methods likely needed to induce and measure TTS in sea turtles, if feasible.

Although work in 2020 was delayed due to permit delays resulting from COVID-19 restrictions, the team secured permits and acquired both turtle species. Initial work focused on refining testing methods, sedation of the animals, identifying variables to be addressed in testing and evaluating baseline threshold for the red-eared sliders. These tests were followed by AEP recordings and initial TTS onset evaluation. During 2021 the project team completed AEP and TTS evaluations using broadband signals in red-eared sliders and eastern painted turtles. Results were collected into a TTS SEL (SPL vs duration) matrix by species. The matrix provides a visual presentation of the test frequency and exposure time by sound pressure level for each animal tested. The team began preparing manuscripts for TTS results by species. Methods for evaluating auditory anatomical effects, such as hair-cell changes, were being reviewed.

During 2022 the team focused on analyzing data from broadband noise TTS testing and building the TTS matrix. Team members also started conducting noise exposures with narrowband sounds and preparing manuscripts for publication as well as working with the Navy's Environmental Compliance team on incorporating data into criteria analyses.

The audiograms and TTS data produced by this research will inform analyses of the effects of sound-producing activities on both freshwater and sea turtles.

Work in 2023 included quantifying potential auditory impacts from noise exposures, finishing testing TTS for higher 1/6 octave (narrow) band noise in the eastern painted turtles, collecting a comparable dataset with the second species (red-eared sliders), addressing additional SPL/exposure duration combinations to build a larger SEL matrix for each fatiguing noise, integrating intermittent noise exposures, and exploring anatomy via MRI and CT to quantify potential auditory impacts from noise exposures. The team continued to work with the Navy's Environmental Compliance team as these data were incorporated into criteria analyses.

Because no TTS data previously existed for turtles, the audiograms and TTS data produced by this research will inform analyses of the effects of sound-producing activities on both freshwater and sea turtles and provide appropriate data when developing the next phase of TTS criteria. The project will also provide protocols that will contribute to future investigations of noise-induced hearing loss in other turtle species, including sea turtles.

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., 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.

Frequency-dependent Underwater TTS in California Sea Lions

Principal Investigator: Ron Kastelein
Project Status: Ongoing, 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 is testing how sounds of different frequencies may affect the underwater hearing of California sea lions (*Zalophus californianus*).

The goals of the project are to

1. Establish underwater behavioral audiograms (hearing thresholds over the entire hearing frequency range of a species) for two more California sea lions. Currently behavioral audiograms exist for only four animals
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 whether exposure measured with grid measurements with hydrophones compares to measuring exposure with a sound recording DTAG on a free-swimming sea lion

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

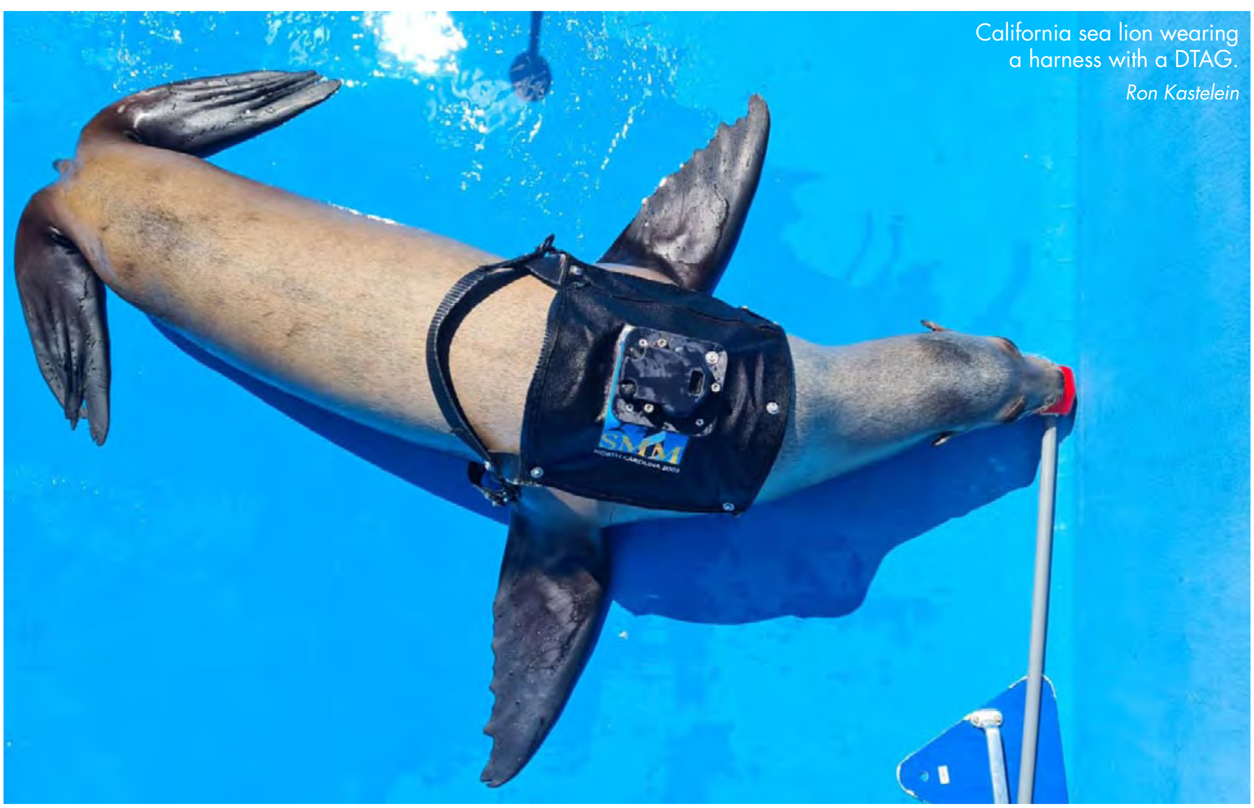
Two California sea lions, an adult female and a young male, with excellent hearing were tested within a pool complex designed for acoustic studies. The animals were exposed to the fatiguing sounds and their hearing was tested pre- and post-exposure. The fatiguing sounds were continuous 1/6th-octave noise 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 is evaluating two frequencies (4 kHz and 8 kHz) with five exposure durations (10, 20, 40, 64 and 80 minutes) with five different SPLs: all duration and SPL combinations leading to the same SEL.

Six duty cycles have been tested: 2.5 (representative duty cycle of 53C sonar), 60, 70, 80, 90 and 100 percent. Assessing duty cycle effect 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.

During 2021, data collection at three additional frequencies—0.6, 1 and 16 kHz—was completed, and 32 kHz testing was initiated. Animal training



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

for a new task, to measure sound exposures with sound recording DTAGs on an animal, was also initiated. The goal of this task is 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 requires training the animal to work with a harness to which the DTAGs are 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 data collection at very low frequencies for the audiograms. The project team also initiated the DTAG data collection effort. The collected data are being used to compare the SPL measurements made with static hydrophones within the pool versus two DTAGs mounted on the back of a swimming sea lion. The team completed initial training needed for the animal to swim with a harness that carried the DTAGs. They recorded all fatiguing sounds used in the TTS study twice with tags on the animal. Each fatiguing sound is tested at three SPLs, as well as measuring an acoustic body shadow for each fatiguing sound frequency. 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 produce the same fatiguing sound as during the previous TTS studies. Two manuscripts were published in 2022 (see the 2022 LMR Annual Report).

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

Work planned for 2024 will focus on finalizing the results from the TTS elicited with 32 kHz and with 40 kHz fatiguing sounds and submitting manuscripts on the results. In addition, the data collected with the DTAGs will be published. The final task will also be initiated in 2024, in which a

California sea lion at SEAMARCO.
Ron Kastelein

sea lion will be trained to accept high-level sound exposure while stationary in front of an underwater loudspeaker for 15 minutes. Previous TTS results that were collected when the sea lion is exposed to 4, 16 and 32 kHz fatiguing sounds while free swimming will be compared to these new exposures to the same fatiguing sound frequencies when the animal is stationed at one location for 15 minutes.

In addition to the hearing and TTS data, this project will provide insights into methods and equipment used during captive animal TTS studies.

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

In addition to the hearing and TTS data, this project will provide insights into methods and equipment used during captive animal TTS studies. The project will provide data that can be used to inform future development of the sound recording part of the DTAG (improve fidelity, reduce directionality, improve the housing), and gives insight in the frequency-dependent effect of body shielding on the sound level of the recordings by the DTAG. The project will also give insight into the potential variations in results of the different exposure methods used in TTS studies: free-swimming exposure or stationary exposure. These types of insights inform future improvements to 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).

Publications

Kastelein, R.A., Helder-Hoek, L., Defillet, L.N., Terhune, J.M., Beutelmann, R. and Klump, G.M. (2023). Masking release at 4 and 32 kHz in harbor seals associated with sinusoidal amplitude-modulated masking noise. *The Journal of the Acoustical Society of America*, 154(1):81-94. DOI 10.1121/10.0019631.

Kastelein, R.A., Helder-Hoek, L., Van Acoleyen, L., Defillet, L.N., Huijser, L.A.E. and Terhune, J.M. (2023). Underwater sound detection thresholds (0.031-80 kHz) of two California sea lions (*Zalophus californianus*) and a revised generic audiogram for the species. *Aquatic Mammals*, 49(5):422-435. DOI 10.1578/AM.49.5.2023.422.

Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds

Principal Investigator: Dorian Houser
Project Status: Ongoing, 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 environmental compliance efforts, broadening the application of AEP results in future criteria development.

PROJECT

This project is working to empirically determine relationships between behavioral hearing and AEP 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 hearing thresholds in the same individuals across the range of hearing, the team will determine the frequency-dependent relationship between behavioral and AEP thresholds. 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 environmental compliance.

The project team is working with a subset of the bottlenose dolphins of the United States Navy Marine Mammal Program (MMP) that are trained for behavioral hearing tests and for participation in AEP studies.

The team's initial focus is on determining AEP threshold "equivalence" corrections for behavioral threshold prediction. Five bottlenose dolphins have been 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.

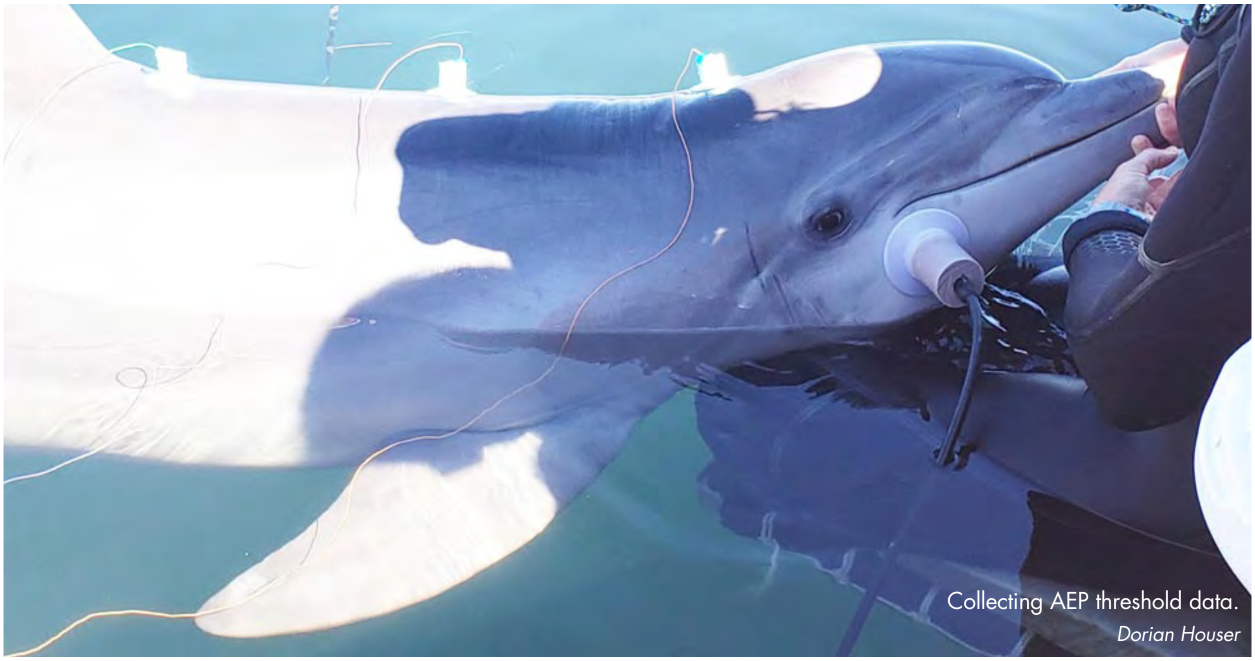
The AEP test scenarios replicate the approaches commonly used with stranded and rehabilitating odontocetes. The methods allow the variability in each AEP method to be determined. Subsequently, the AEP thresholds obtained under each test condition are compared to the behavioral threshold collected on the same day to determine frequency-specific differences between the AEP and behavioral results. It is intended to use the differences between the behavioral and AEP thresholds to adjust the AEP thresholds such that they become effectively behaviorally equivalent.

Based on the results, equivalence corrections will be 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 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 and initiating behaviorally equivalent audiograms.

In 2023, 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 also drafted. To augment the study, a young dolphin for which AEP thresholds were collected but for which

Dolphin performing AEP.
Dorian Houser



Collecting AEP threshold data.
Dorian Houser

no behavioral thresholds have been measured was trained for a behavioral hearing test. This test should be completed in early 2024 and will provide a good assessment of how well the equivalence corrections predict behavioral thresholds. Additional work will include coordinating with National Marine Fisheries Service and U.S. Navy as to the potential implementation of behaviorally equivalent audiograms in Navy environmental analyses.

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

The behaviorally equivalent audiograms should 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 the development of 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 environmental 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 serves as the chair of an American National Standards Institute/Acoustical Society of America (ANSI/ASA) committee on Animal Bioacoustics (S3/SC1). 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).

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).

In addition to the goals described above, the relative loudness of multicomponent signals will be


Killer whale.

compared to pure tone (i.e., single frequency) signals to determine if summation across the frequency spectrum occurs. 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 "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 environment 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 audiograms (i.e., detection thresholds as a function of frequency) for different duration signals. It will also enable estimates of the temporal integration time (i.e., how quickly the brain responds to the signal).

2. **Masked duration-dependent detectability of tones and multi-component signals.**
   This experiment will test how signal detection in noise depends on sound duration and compares broadband sounds to tones. The goal is to provide data indicating how the harmonic components in Navy sonar signals, as well as 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, and data analyses were ongoing at the close of 2022.

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).

Work in 2023 included new data collection for experiment 1 and the newly defined experiment 2, data analyses and manuscript preparation. One manuscript was published in 2023 (see Publication sidebar). Two additional manuscripts are planned during the remainder of the project.

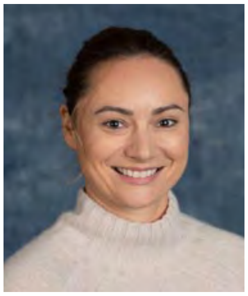
National Marine Mammal Foundation research assistant and SeaWorld killer whale zoological specialist (trainer) Kayla Nease.

This study will provide the necessary data to modify current auditory weighting functions to include both pulsed tones and broadband sounds. Results will be provided in project reports and in manuscripts to be submitted for peer-reviewed publication.

Investigating auditory perception as a function of signal duration for killer whales will also provide data for other large odontocetes such as beaked whales and sperm whales.

The data will support the Navy at-sea environmental compliance community in environmental criteria development by improving auditory weighting functions used in the 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, and bandwidth-dependent, auditory weighting functions will support perceived loudness estimations for a broad range of signals. Investigating auditory perception as a function of signal duration for killer whales will also provide data for other large odontocetes such as beaked whales and sperm whales, because killer whales are currently the best hearing surrogate for this group.

About the Principal Investigators



Alyssa Accomando started this project when she was a scientist and Deputy Director of Environmental Stewardship with the National Marine Mammal Foundation and is currently a scientist with the Naval Information Warfare Center Pacific (NIWC). Dr. Accomando conducts both basic and applied research that primarily focuses on auditory processing and perception in echolocating animals. She has also performed research investigating biological underpinnings of sound production and reception, as well as the effects of explosions on marine fishes. She earned her Ph.D. in neuroscience from 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

Branstetter, B.K., Nease, K., Accomando, A.W., Davenport, J., Felice, M., Peters, K. and Robeck, T. (2023). Temporal integration of tone signals by a killer whale (*Orcinus orca*). *The Journal of the Acoustical Society of America*, 154(6):3906-3915. DOI 10.1121/10.0023956.

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: Ongoing, Project 51

NEED

N-0238-21: Understanding Marine Mammal Hearing and Behavioral Response to Continuous 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 ctinuous 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 is measuring 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 focus is 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

Bottlenose dolphin.
Todd Pusser, NOAA

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.

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 focus is to determine if equal energy exposures result in equal TTS, independent of exposure duration.

The project goals are 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 is collecting 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 are using rapid behavioral and AEP procedures for determining hearing thresholds so that thresholds can be measured on a short time scale relative to hearing recovery after 28-kHz noise exposure.

The fatiguing stimuli used to induce TTS are both CW tones and FM tones with bandwidths characteristic of CAS. It is expected that TTS effects will 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 is 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 79), but frequency-shifted to match the region of best sensitivity in the dolphin's hearing curve.

The 3-kHz stimulus is a narrower-band one-third octave linear FM sweep based on the actual characteristics of U.S. Navy sonar.

Intermittent hearing tests are being 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 is being monitored by the attending veterinarians and animal care staff at the Naval Information Warfare Center, Pacific over the course of the study.

These results will support the Navy's acoustic effects criteria development.

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 76 exposures (and 34 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. 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. Noise exposure sessions with one dolphin to this point have suggested that TTS onset SELs at 3 kHz are higher than those for 28 kHz, consistent with the less sensitive hearing (higher thresholds) below approximately 10 kHz in toothed whales.

Testing in 2024 will continue 3-kHz noise exposures and will include an additional dolphin subject that is currently training for the project. The results of the project will support the Navy's acoustic effects criteria development.

About the Principal Investigator

Jason Mulsow is Deputy Director of the Biologic and Bioacoustic Research program at the National Marine Mammal Foundation (NMMF). 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

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.

New Start Projects

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

Principal Investigators: Frans-Peter Lam, Petter Kvadsheim, Patrick Miller
Project Status: New start, 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 continuous 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 is part of a broader international research consortium that 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, humpback whales and bottlenose whales
2. Investigate if responses from short duration experiments predict responses from longer duration exposures conducted over an operationally relevant duration.

Of particular interest are species that: (1) vocalize in the frequency band of the sonar (e.g., killer whales and humpback whales), because CAS has higher potential for masking, and (2)

George Sato, Norwegian Animal Research Authority permit 23/110085

Alec Burslem

have been shown to be particularly sensitive to PAS (e.g., beaked whales).

The project is supported in partnership with the LMR program and Canadian, French, Norwegian, Icelandic and Dutch naval authorities and research organizations. Coordinating with this international effort will help both the U.S. Navy and allies in the North Atlantic Treaty Organization (NATO).

The project plans multiple 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 will include a DTAG3 core unit, VHF transmitter and the new GPS-ARGOS unit built by Lotek. The source vessel will be equipped with a goniometer-receiving system for real time reception of ARGOS transmissions, and with the decoding system for GPS location data. For longer term tracking, satellite tags (SPLASH10-F-333B) will be 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.

This project will provide valuable data to support new CAS vs PAS assessments.

The first of two planned field efforts, 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 exposures (two CAS and two PAS) 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, environmental conditions and sonar signals. Due to technical issues with the sonar source the team had to switch from 1.3–2.0 kHz high frequency modulated signals (transmitted at energy source level of 201 dB re 1 $\mu Pa^2 s m^2$ during both CAS and PAS) to 4–6 kHz high frequency modulated signals (transmitted at energy source level of 184 dB re 1 $\mu Pa^2 s m^2$ during both CAS and PAS). Data analyses were underway at the close of 2023.

During 2024, the project will continue data analyses, complete a cruise report on the 2023 work and plan and conduct the second field effort. Initial data analyses and results will be completed following each field effort with final products expected by the close of 2026.

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

Current environmental 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).

Measuring Behavioral Responses of Cuvier's Beaked Whales to Continuous Active Sonar in the Atlantic

Principal Investigator: Douglas Nowacek
Project Status: New start, Project 67

NEED

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

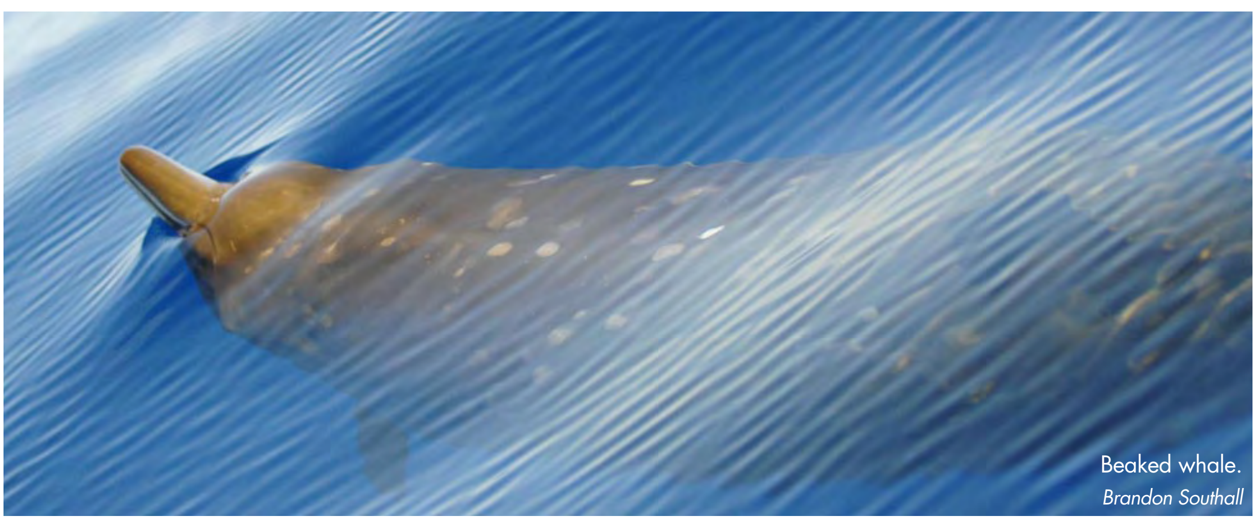
It has been noted from previous behavioral response studies that signal type and duration of Navy sonar signals may play a role in observed responses in marine mammals. In 2017, LMR began investing in studying and collecting behavioral response data to continuous active sonar (CAS) as part of the third 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 the Cuvier's beaked whale (*Ziphius cavirostris*), also known as the goose-beaked whale, 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 signals MFAS activities on Cuvier's beaked whales and 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 Cuvier's beaked whales to MFAS activities using traditional lower duty-cycle sonar signals. The team will also use visual and photographic confirmation of the composition of the beaked whale social groupings.

The experimental protocols include a pre-exposure period during which baseline behavioral data are



Beaked whale.
Brandon Southall

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 and/or the project team will deploy a simulated CAS source. Protocols include full control CEEs (no CAS exposure) with focal tagged and followed animals where possible on days without CAS exposure. 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.

Results of this effort will support direct comparison between responses to CAS signals and to conventional, lower duty-cycle MFAS 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 Cuvier's beaked whales. 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. The team relocated tagged individuals, which contributed photo-ID data that offer insights on social group compositions and social interactions.

Field plans for 2024 include coordinating with Navy ships to conduct CAS CEEs. Initial reports will be submitted following each field effort and during the analytical phase in year three. A final report is scheduled in year four.

The primary products of this study will be empirical measurements of behavioral responses of Cuvier's beaked whales 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 environmental compliance as well as the broader scientific and conservation communities. The results will be directly available for use in future Navy behavioral risk functions and permitting processes.

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).

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 five ongoing projects and one new start project.

The ongoing projects are

1. Project 42—ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation
2. Project 49—Combining Global OBS and CTBTO Recordings to Estimate Abundance and Density of Fin and Blue Whales
3. Project 60—Historic ARP and HARP Passive Acoustic Recording Archiving with National Centers for Environmental Information (NCEI)
4. Project 62—Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses
5. Project 65—Using Passive Acoustic Tracks from a Navy Array to Study Large Whale Behavior in the North Atlantic.

The new start project is

1. Project 63—Cetacean Caller-ID [CETACID]: Validating Approaches for Identifying Focal Communication Signals Using Acoustic Recording Tags.

MC3 Riley Gasdia

Ongoing Projects

ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation

Principal Investigator: Tiago Marques
Project Status: Ongoing, 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 data sets 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 is 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 is to determine the most appropriate cue rates to use in different contextual settings. The project will produce a comprehensive set of recommendations of the most appropriate means by which to advance this field to meet Navy needs. This information will be made publicly available to the wider scientific community involved in estimating density from passive acoustics.

The project tasks include

- Identifying, reviewing, compiling and providing open access to all data available on cue rates (and their variability) across deep diving and baleen whale species
- Estimating cue rates from monitoring tag data
- Exploring the factors that determine both cue rate stability and variability over time and space
- Investigating inter-click interval (ICI) patterns for deep divers (e.g., Cuvier's and Blainville's beaked whales)
- Evaluating impacts of cue rate variability on density estimates from cue-based methods
- Applying these methods to species of interest for the Navy.

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

During its start-up in 2020, the project initiated several tasks. First was 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 sources. (See the 2021 LMR Annual Report for

Narwhals.
Mads Peter Heide-Jorgensen, NOAA

a list.) The ACCURATE team has been collaborating with many other teams that have relevant data and information on the topic, with a natural focus on, but not exclusive to, other LMR-funded projects.

Team members also began working 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 include Blainville's beaked whales (*Mesoplodon cavirostris*), Cuvier's beaked whales (*Ziphius cavirostris*), pilot whales (*Globicephala melas*), sperm whales (*Physeter macrocephalus*) and narwhals (*Monodon monoceros*). Cues and cue types from each processed tag are being counted to obtain a cue rate per tag. The estimated cue rate per tag will be extrapolated into a simple cue rate per species. Where possible, factors affecting cue rate will be identified.

Work in 2021–22 focused on furthering the bibliographic review and tag data processing and analyses. A draft document summarizing the bibliographic review results, including the synthesis of identified datasets, was developed and circulated for comment. A revised version was in review at the end of 2023. A total of 860 tags have been identified for processing. For sperm whales alone, approximately 170 tags have been processed producing almost eight million echolocation clicks to be analyzed. Data from the tags are informing subsequent tasks, including identifying factors that influence cue rate and caller identification for individual whales.

Work on other ACCURATE tasks continued in 2023 as described below.

Team members assessed factors influencing cue rates and worked on refining methods to identify cue rates from proxy data, evaluating deep diver cue rate variability and defining detector/classifier implications for cue rates. The analysis of sperm whale tag data during 2023 continued to focus on sound production rates and how to estimate cue rates from tags without acoustic recorders. A paper comparing different methods for estimating cue rates from tag data using sperm whales as an example was published (Marques et al. 2023. See Publications sidebar). Detailed analyses of narwhal tags data were also conducted. A manuscript about narwhals' cue rates using Acousonde data from Greenland was submitted in 2023, received positive reviews and is expected to be published in 2024. Another narwhal-focused manuscript is expected to be submitted in 2024. A third narwhal-related manuscript planned for 2024 will report on a new automatic detector for narwhal echolocation clicks developed by a Ph.D. student.

Cue rate estimation work ongoing in 2023 included estimating cue rates for baleen whales by analyzing acoustic and auxiliar sensor data from right whales, blue whales, fin whales and humpback whales. The team continued work to evaluate data from the different types of tags (i.e., time-depth recorders vs acoustic tags), refine methods and determine how proxy data could be used to estimate cue rates. A paper will be submitted in early 2024 describing the conditions under which one might be able to identify the tagged animal as the calling animal for baleen whales. Other papers investigating caller identification in humpback whales have been submitted and are expected to be published in 2024.

Considerable work on deep divers (including beaked whales and sperm whales) detected on bottom-mounted sensors was developed during 2023. One of the work threads resulted in a manuscript published on geographic differences in echolocation clicks in Blainville's beaked whales (Baumann-Pickering et al. 2023. See Publications sidebar), and additional papers about sperm whales are expected to be submitted for publication in 2024.

An analysis of sperm whale click rates from towed arrays has been submitted and positive feedback received. 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. These results will be published during 2024.

Evaluations of how signal detector/classifiers might affect cue rate estimations continued in 2023. The team conducted simulations with data from Blainville's beaked whales and sperm whales to evaluate how the detector/classifiers could affect the actual definition of a cue rate (e.g., single clicks, multiple clicks in close succession). Results of this work are targeted for publication in 2024.

The many ACCURATE outputs currently underway are projected to be finalized and submitted as manuscripts during 2024. The ACCURATE website (accurate.st-andrews.ac.uk) will continue to be populated with project outputs, in both scientific and outreach formats. The website is expected to be nearly final by the end of 2024 and that it will provide a convenient hub for ACCURATE outputs in a single accessible location to the wider community for years to come.

Sperm whale.
Wayne Hoggard, NOAA

Marine mammal density estimates are a critical element of the Navy's acoustic effects modeling, which supports environmental compliance. Passive acoustic monitoring potentially offers a cost-effective method to generate density estimates for a wide range of species across Navy priority areas.

By understanding cue rates and cue rate stability, this project will advance the practical application of PAM-DE for Navy purposes.

By understanding cue rates and cue rate stability, this project will advance the practical application of PAM-DE for Navy purposes. The resulting repository of synthesized data will support future density estimation from passive acoustic monitoring.

About the Principal Investigator

Tiago A. Marques is a senior 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 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).

Publications and Products

Baumann-Pickering et al. 2023 Geographic differences in Blainville's beaked whale (*Mesoplodon densirostris*) echolocation clicks. *Diversity and Distributions*, 29(4):478-491. DOI 10.1111/ddi.13673.

Marques, T. A., Marques, C. S. and Gkikopoulou, K. C. 2023 A sperm whale cautionary tale about estimating acoustic cue rates for deep divers. *The Journal of the Acoustical Society of America*, 154(3):1577-1584. DOI 10.1121/10.0020910.

Video

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

Publications acknowledging ACCURATE contributions

Macaulay, J.D.J., Rojano-Doñate, L., Ladegaard, M., Tougaard, J., Teilmann, J., Marques, T.A., Siebert, U. and Madsen, P.T. (2023). Implications of porpoise echolocation and dive behaviour on passive acoustic monitoring. *The Journal of the Acoustical Society of America*, 154(4):1982-1995. DOI 10.1121/10.0021163.

Buckland, S.T., Borchers, D.L., Marques, T.A. and Fewster, R.M. (2023). Wildlife population assessment: changing priorities driven by technological advances. *Journal of Statistical Theory and Practice*, 17(2):20. DOI 10.1007/s42519-023-00319-6.

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

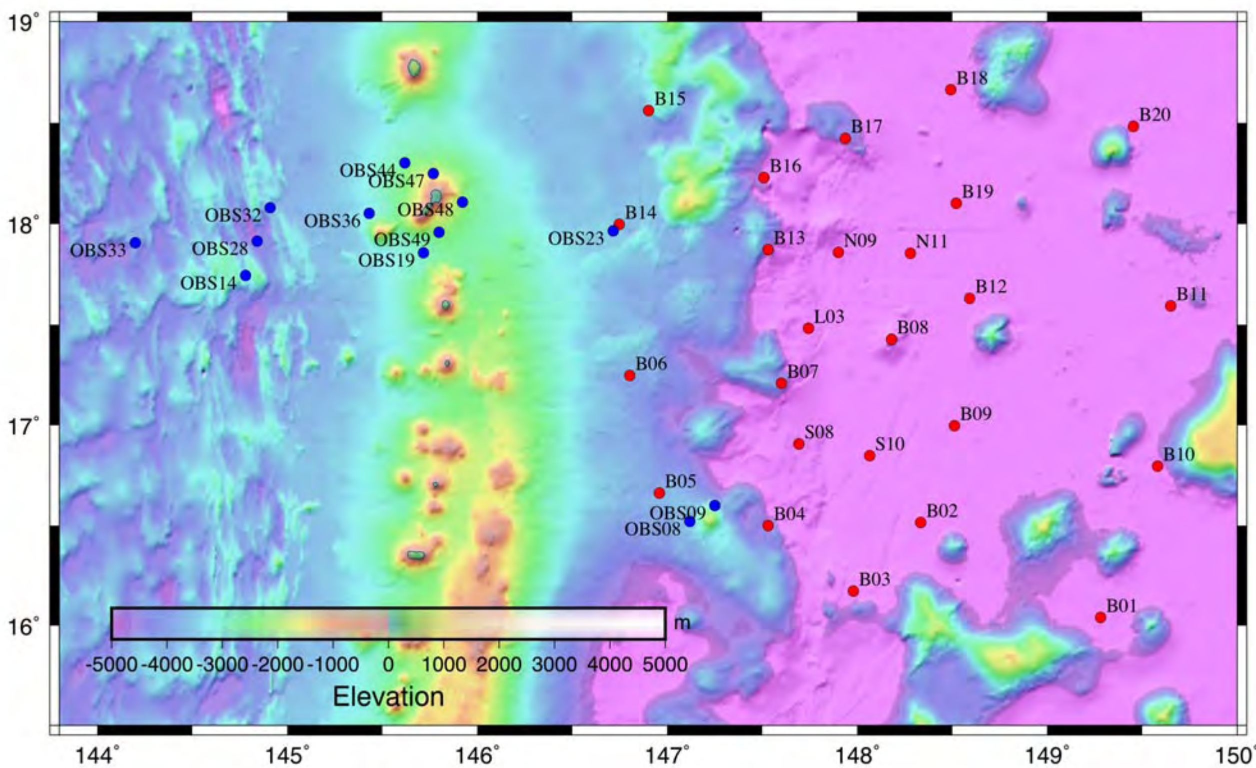
NEED

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 data sets.

PROJECT

This project is working to demonstrate and refine a suite of methods previously developed to obtain



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.

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.

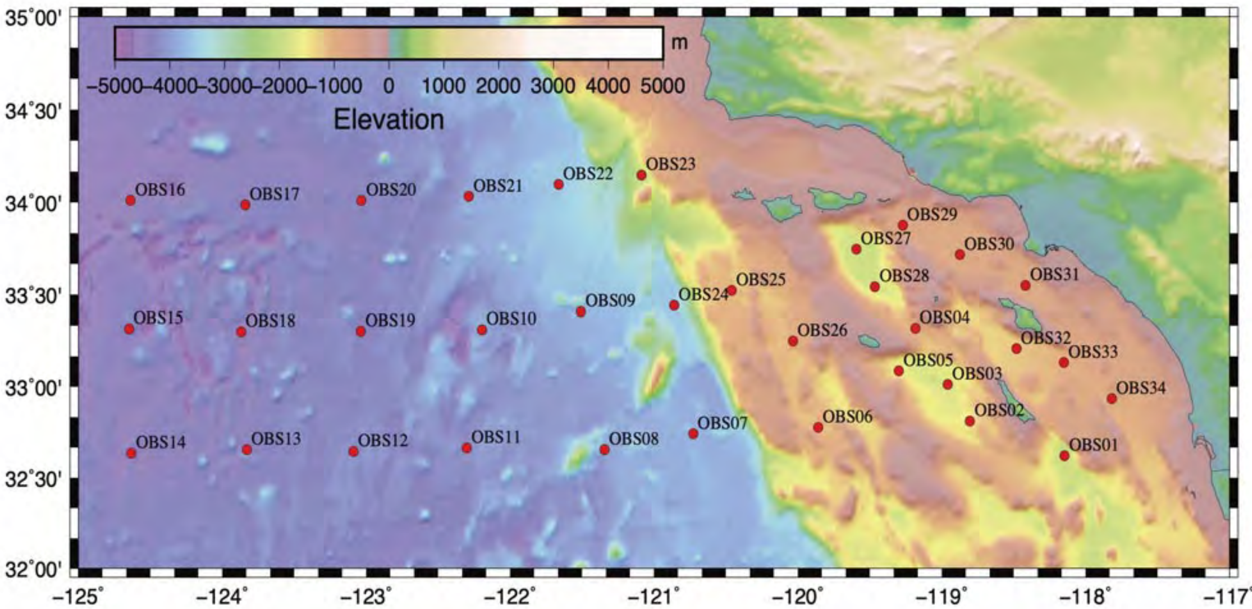
This work is co-funded by LMR and ONR MMB and will build on information compiled under previous ONR MMB funding. The early tasks, funded by ONR MMB, include reviewing existing OBS and CTBTO IMS datasets from around the world, selecting a set of case study datasets containing blue whale and/or fin whale 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 will focus 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.

The project began with the ONR MMB-funded tasks of comparing ranging methods and developing methods for density estimation. Work in 2023


Blue whale.
Cascadia Research Collective



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.

has continued these tasks but also has 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. A student was also recruited to begin a Ph.D. project in 2024 focusing on ecological and behavioral questions using the datasets.

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

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 and Kerri D. Seger (Applied Ocean Sciences, LLC, VA, USA), Luis Matias (University of Lisbon, Portugal) and 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

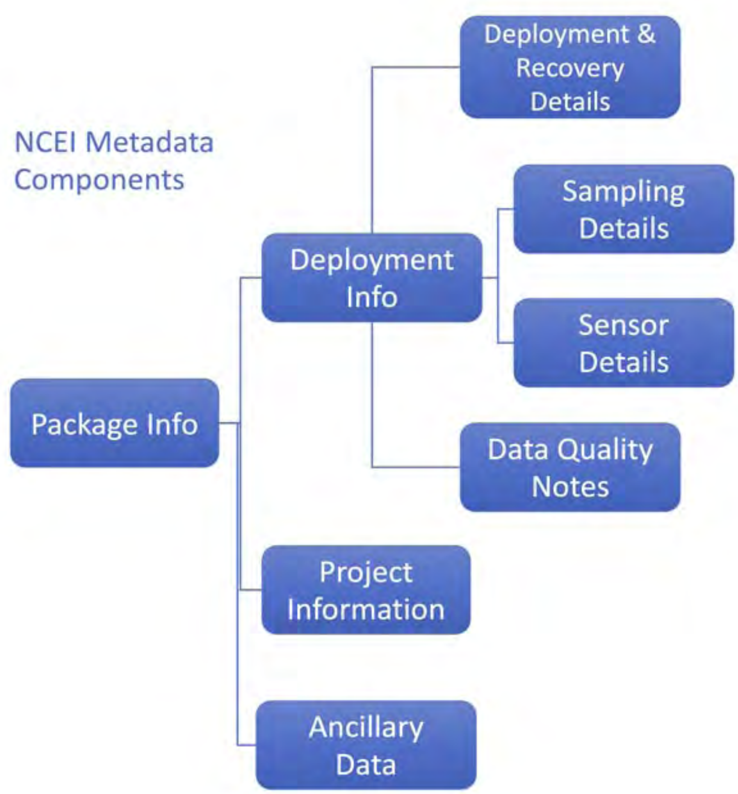
With prior Navy funding, the Scripps Whale Acoustic Laboratory has collected an extensive set of passive acoustic data using Acoustic Recording Packages (ARPs) and High Frequency Acoustic Recording Packages (HARPs). These data are at risk of deteriorating or being lost without proper means of archiving the data. This project will focus 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 will collaborate 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.

This project will focus on preserving the oldest sets of data, collected between 1999 and 2009.

1. **Archiving Data**

   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 pre-

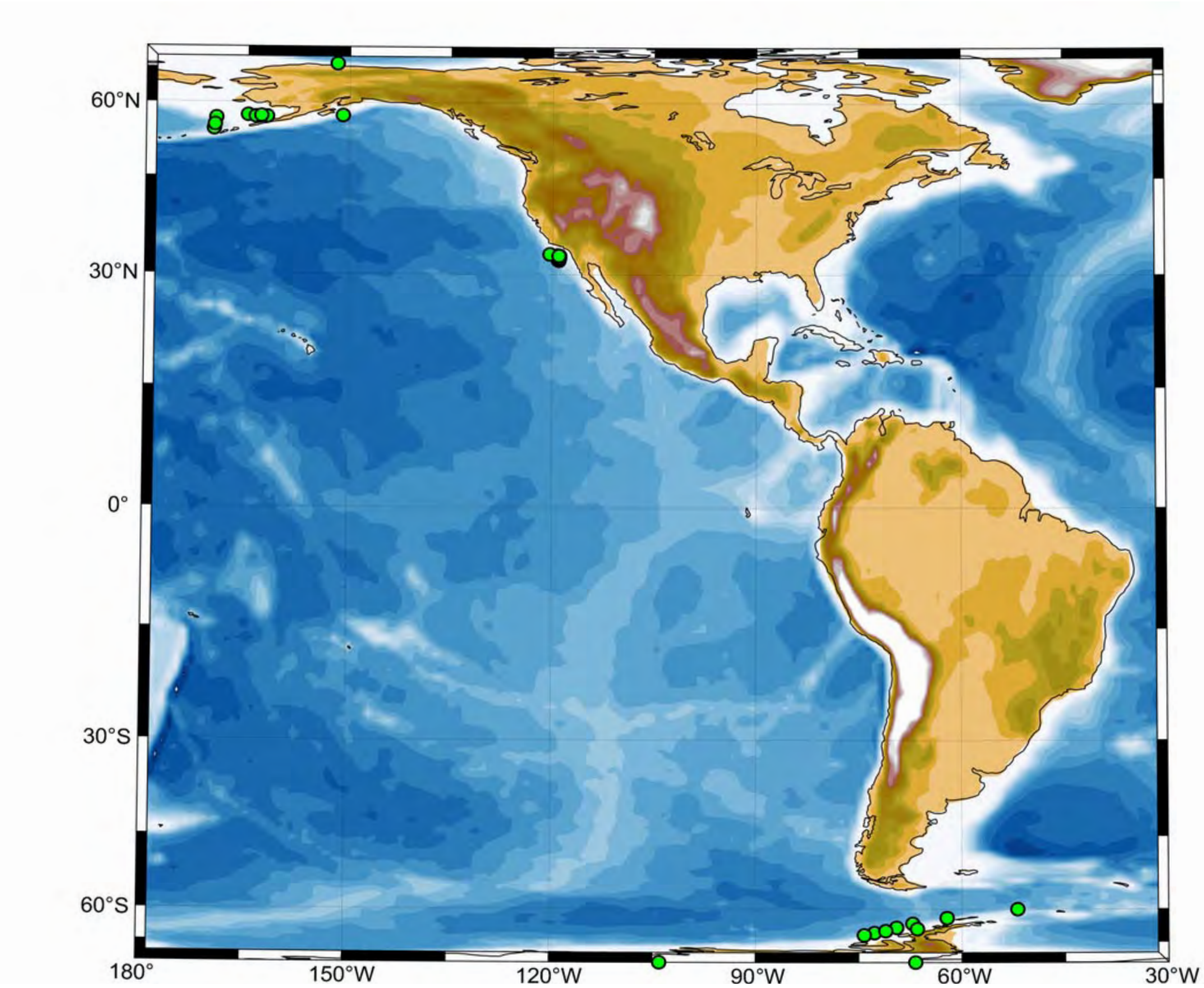


pared for packaging and security screening. Once the data are received back from security screening, work in 2024 will include processing and packaging that data for submittal to NCEI for archiving.

In collaboration with NCEI software developers, a programmatic workflow tool ("Sheet PassivePacker") was developed to automate the process of compressing and packaging acoustic datasets for the NCEI archive (see also Project 66, page 122). Three test packages not requiring security screening were packaged using this workflow and shipped to NCEI, where they are now publicly discoverable online. In addition, sonobuoy data collected from 2005–2023 CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruises was extracted and packaged for submission to NCEI.

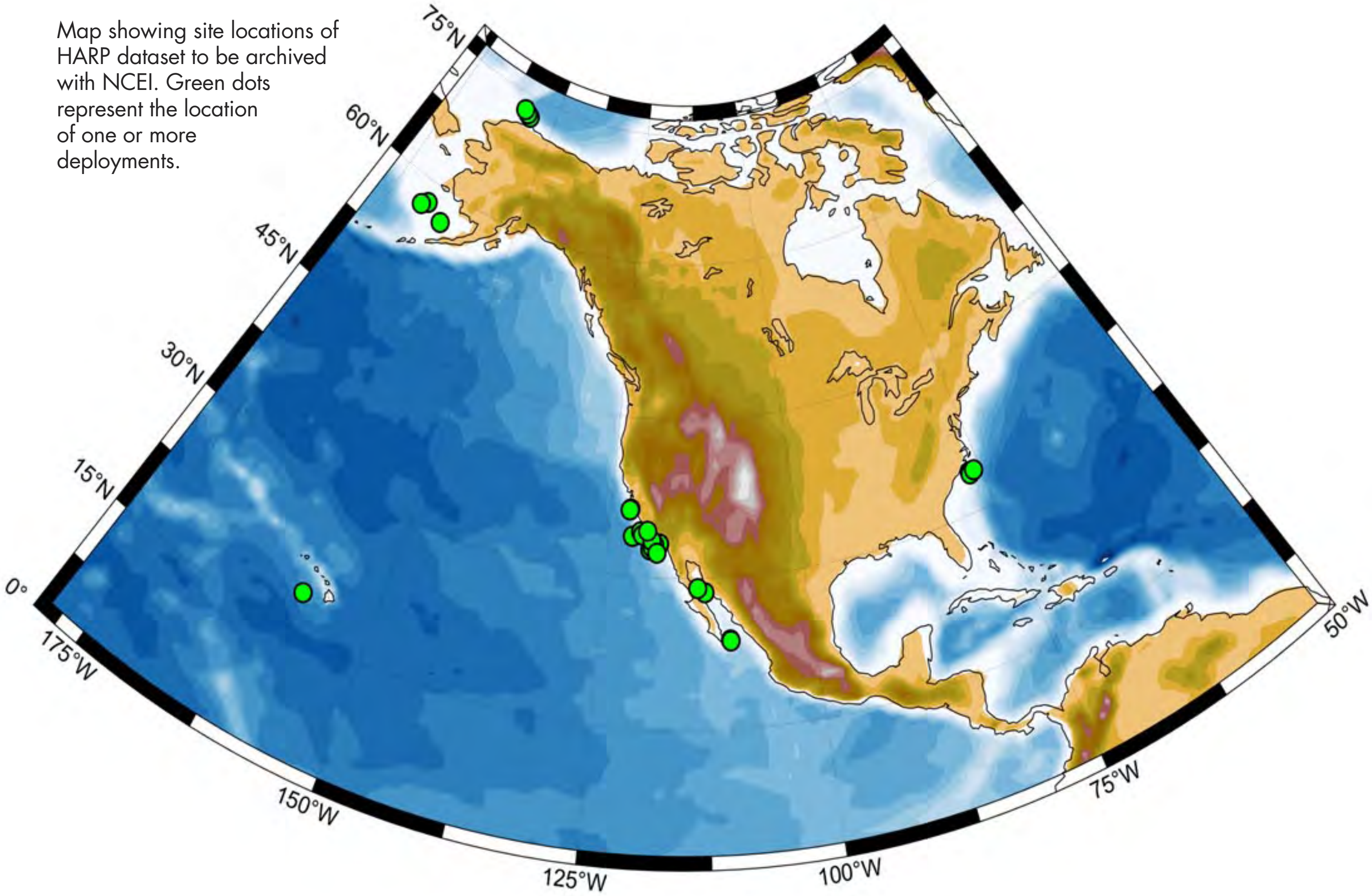
2. **Case Study Project**

   Datasets recorded in Beaufort and Arctic waters between 2004 and 2009 were identified in collaboration with NCEI as inputs for the case study project. Soundscape metrics were computed for these datasets using the software package Manta. These were packaged using NCEI's PassivePacker. Project members participated in a series of virtual



Map showing site locations of ARP dataset to be archived with NCEI. Green dots represent one or more deployments.

Map showing site locations of HARP dataset to be archived with NCEI. Green dots represent the location of one or more deployments.

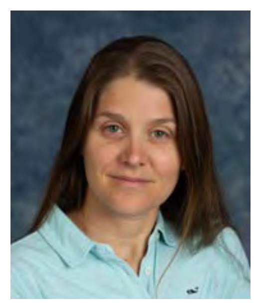


project meetings and an in-person project meeting at NCEI to provide insight on the feasibility of product generation and how these products could be used for interdisciplinary research. The project lead also assisted an NCEI contractor with applying existing machine learning algorithms to these products for data classification.

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 collaboration with NOAA Southeast Fisheries Science Center for passive acoustic data collected in the Gulf of Mexico, 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 collaboration 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 Navy NOAA project, SanctSound.

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

Humpback whale.
Elliott Hazen, NMFS

Fin whale.
Roger Hewitt, NOAA

both 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 Sound-Coop team (see Project 66, page 122), 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 that 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 will focus on integrating the Raven-X technologies into the NUWC/NIWC computing environments. 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 will continue to develop computer code to integrate existing acoustic detection, classification and location (DCL) algorithms into Raven-X. As an additional case study, the team also plans to use Raven-X to process seven years of data from the Pacific Missile Range Facility hydrophone array to obtain fin whale calling data.

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

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.

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

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

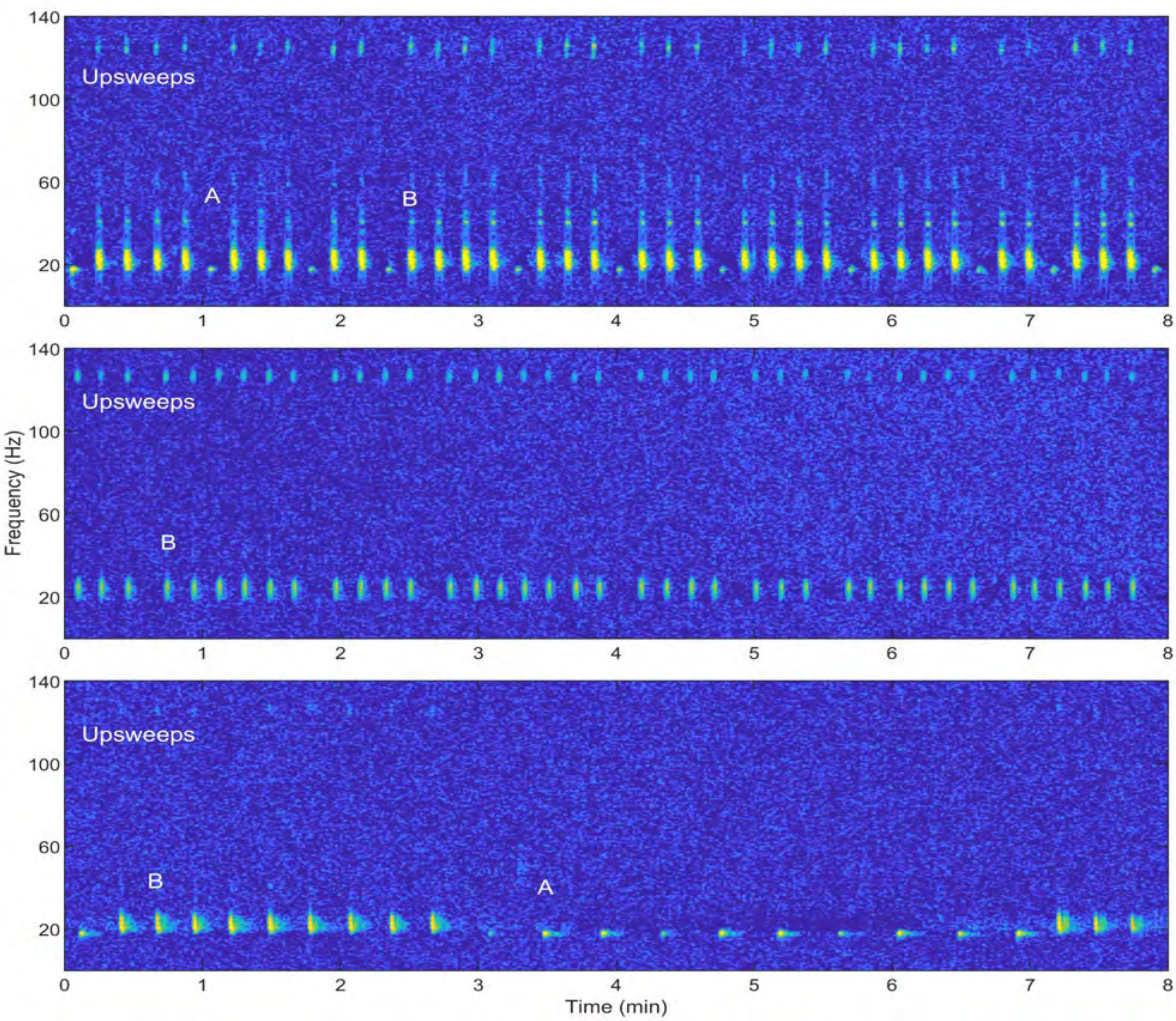
NEED

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

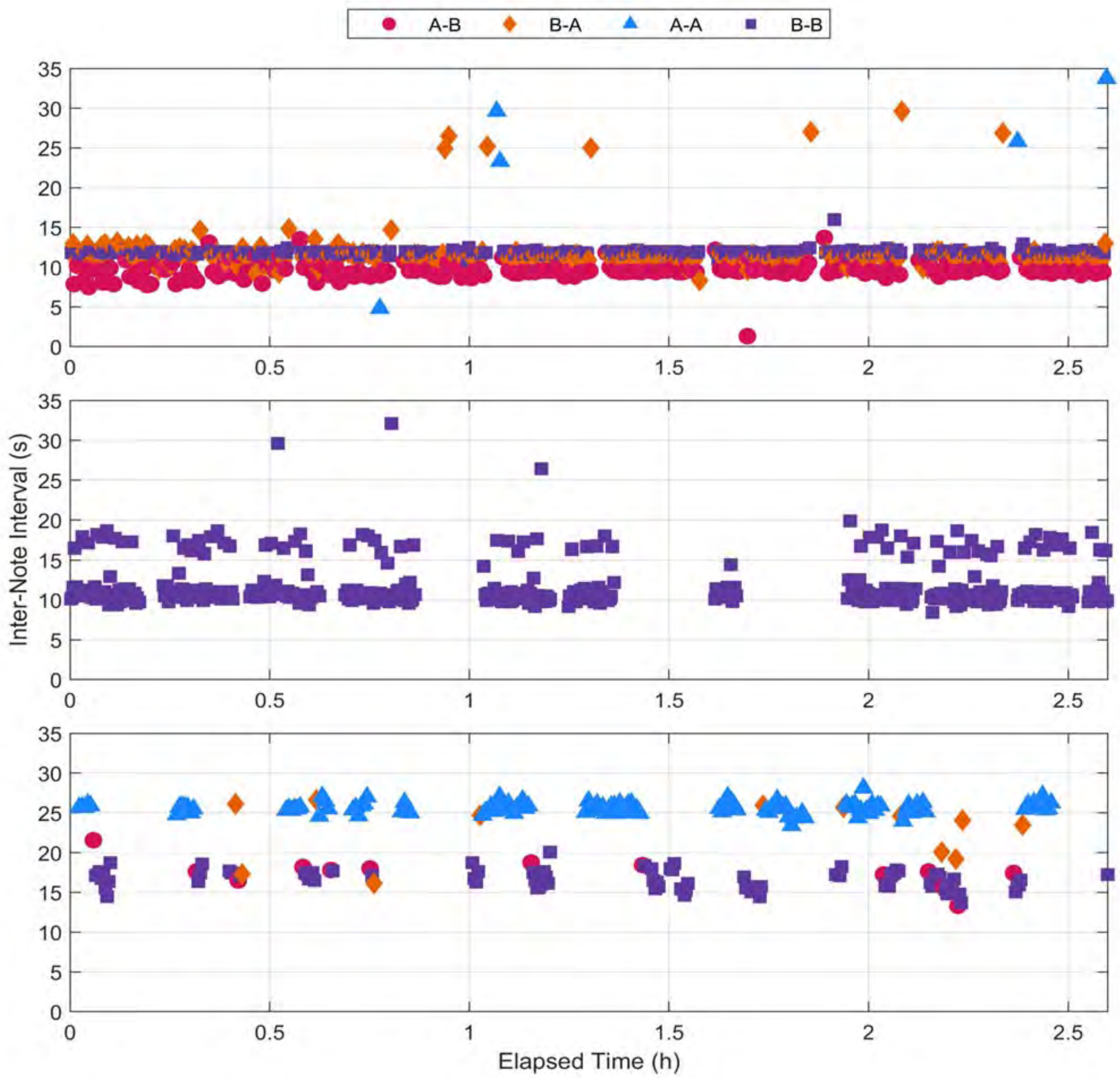
The Navy is interested in developing methods to improve the efficiency of processing and analyzing marine species data and providing cost effective solutions to enhance marine species monitoring capabilities (e.g., detection and classification algorithms, passive acoustic monitoring automated processing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

PROJECT

This project is demonstrating the utility of the Navy's passive acoustic marine mammal monitoring data system, M3. It is building from a project that was funded by the Department of Defense Science, Mathematics, and Research for Transformation (SMART) SEED grant program using M3 data to analyze behavioral responses



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



Inter-note interval (INI) measurements from the three example fin whale songs shown in the spectrograms. Note that the duration of these plots is the entire recording while the spectrograms were showing a short segment of each recording.
Guazzo et al., In Review

to seismic surveys. This project will involve two tasks: (1) continue the analysis of behavioral responses to seismic surveys, and (2) analyze fin whale vocalization behavior in the North Atlantic, including defining cue rates for Atlantic fin whales.

The M3 dataset contains 20 years of passive acoustic monitoring and tracking data collected from bottom-mounted sensors.

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

  The analysis focuses on segmenting the passive acoustic tracks into regular intervals and categorizing each interval into a behavioral state based on speed: fast or slow. The behavioral state will be modeled as a function of time of day, relative position of the seismic vessel and air gun status (on or off). These models will be used to test the hypothesis that whale behavior changes based on these covariates, specifically that whales swim faster when air guns are on and when the vessel is closer to them.

- **Task 2: Previously collected recordings of fin whale tracks will be processed to automatically detect every fin whale note**
  The resulting fin whale dataset will be 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 will then be 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 will help 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. After the project transitioned to LMR funding, the work 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, which is in review.

In 2024, the fin whale song research will be presented at the Ocean Sciences Meeting as a comparison between the song patterns observed in the North Atlantic and those on the Pacific Missile Range Facility (PMRF) off Kauai, Hawaii in the central North Pacific. Work will be refocused on Task 1 and a report of the findings will be completed.

Project outcomes will include a process for securely handling and analyzing data from the M3 system. One manuscript is anticipated from this project, providing fin whale cue rate and song pattern results. A report is also anticipated detailing the observed behavioral responses of large whales to seismic air guns.

The project will help 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 will also contribute to improved analysis of acoustic data needed for environmental compliance assessments.

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 behaviors.

New Start Project

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

Principal Investigator: Frants Jensen
Project Status: New Start, 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 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 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.

A humpback whale fitted with a DTAG3 sound and movement recording tag.
Susan E. Parks, permit 18059 in collaboration with NOAA Stellwagen Bank National Marine Sanctuary

- **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 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, page 33) that is 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 made significant progress toward establishing a database of baleen whale calls with synchronized audio and accelerometer data. The database will be hosted on GitHub, with custom-made software tools for exporting individual sound and sensor files along with metadata from tag folders to the database, and with separate tools to visualize and analyze data within the database. Datasets brought into the system in 2023 include blue whale (one dataset), South Atlantic right whales (three datasets), sei whales (one dataset) and humpback whales (five datasets with songs, five datasets with social calls). The team also completed the first field effort to collect data to validate call identification methods. This work deployed 20 DTAG4 tags on humpback whales, including whales in three small groups and one pair with simultaneously tagged whales suitable for caller-ID validation.

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

For higher-frequency species where the accelerometer method may not work well, other tools are needed. Here, the team plans to work 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. These datasets include calls from 23 different animals in six social groups, from which 1,499 focal calls were identified. The datasets include dense bouts of calls that frequently overlap and thus represent one of the more challenging scenarios for caller identification. The team also completed its first bottlenose dolphin field season and tagged four animals, including one simultaneously tagged mother-calf pair.

Work planned for 2024 includes two field efforts, one in Sarasota Bay (bottlenose dolphins) and the other at Stellwagen Bank (humpback whales and fin whales). The team will also focus on completing its multi-species database of baleen whale calls and initiating development of baleen whale caller-ID algorithms.

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).

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 environmental research and data collection. These technology investments enable efficient and cost-effective implementation of the Navy's MSM program in support of the Navy's environmental compliance and permitting processes.

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 four ongoing projects. There were no new projects in this investment area in 2023.

The ongoing projects are

1. Project 41—Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags
2. Project 56—Integration and Field Evaluation of the Next Generation High-fidelity Sound and Movement Tags to Investigate Behavioral Response
3. Project 57—Demonstrating Suction-cup Tag Systems to Support Behavioral Response Studies
4. Project 59—Long-term Sparse Array Localization Feasibility Study using a SonarPoint System.


MC Seaman Kaleb Birch

Ongoing Projects

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

Principal Investigator: Russ Andrews
Project Status: Ongoing, 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 is building on previous Office of Naval Research-funded efforts 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. The project team is exploring attachment mechanisms that are

- 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 is organized into four separate phases, with implementation of each 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

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

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 comparisons of 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 can 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 are the terminal anchor and attachment materials. Design 1 uses an elastic connection between a more tissue-friendly anchor and an off-the-shelf LIMPET satellite tag external package. Design 2 uses 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. The prototype designs met all defined testing criteria, qualifying both for field demonstration.

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.

After demonstrating the robustness of the redesigned tag holder/insertion device, 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 opportuni-

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

ties, but four of the Design 1 elastic anchors system 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. The final step in Phase 2 is to conduct field tests in Southern California on fin, blue or beaked whales in spring 2024.

Improved attachment mechanisms will improve the Navy's ability to monitor cetaceans before, during and after exposure to Navy sources.

Improved attachment mechanisms that support recording the movements and behavior of cetaceans over longer periods of time, and more consistently, than is currently possible will improve the Navy's ability to monitor cetaceans before, during and after exposure to Navy sources. This will enable the Navy to develop behavioral response functions that are more closely aligned to the statutory definition of take for military readiness activities.

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 more than 23 years. His most recent focus has been using remotely deployed satellite tags to study beaked whale ecology and behavioral responses to anthropogenic sources of sound.

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, improved equity in the research community 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.

This project is focused on integrating next generation electronics for high-fidelity sound and movement tags, a valuable asset for Navy marine species monitoring.

Work falls into three key tasks:

1. **Next generation tag integration**
   The next generation low-power tag electronics (DTAG4) will be used to enhance the performance of tags in the lease pool tag system.

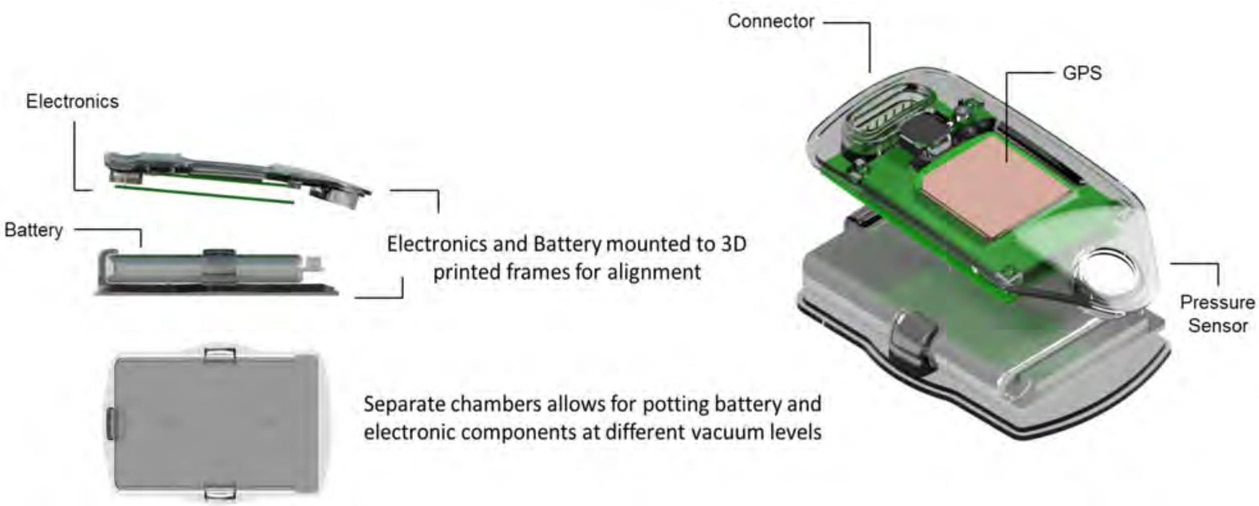


Figure 1: An illustration of the next generation electronics used for the 2023 DTAG4. 3D printed structures are used to position the sensors, electronics and battery for tag assembly.

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, system prototyping and system testing to evaluate the new designs.

2. **Lab-based and dedicated field testing**
   The initial tag prototypes will be used for lab-based testing to evaluate design performance and identify performance bounds for the system. Lab-tested tag designs will then be subjected to field testing to characterize performance and identify design limitations

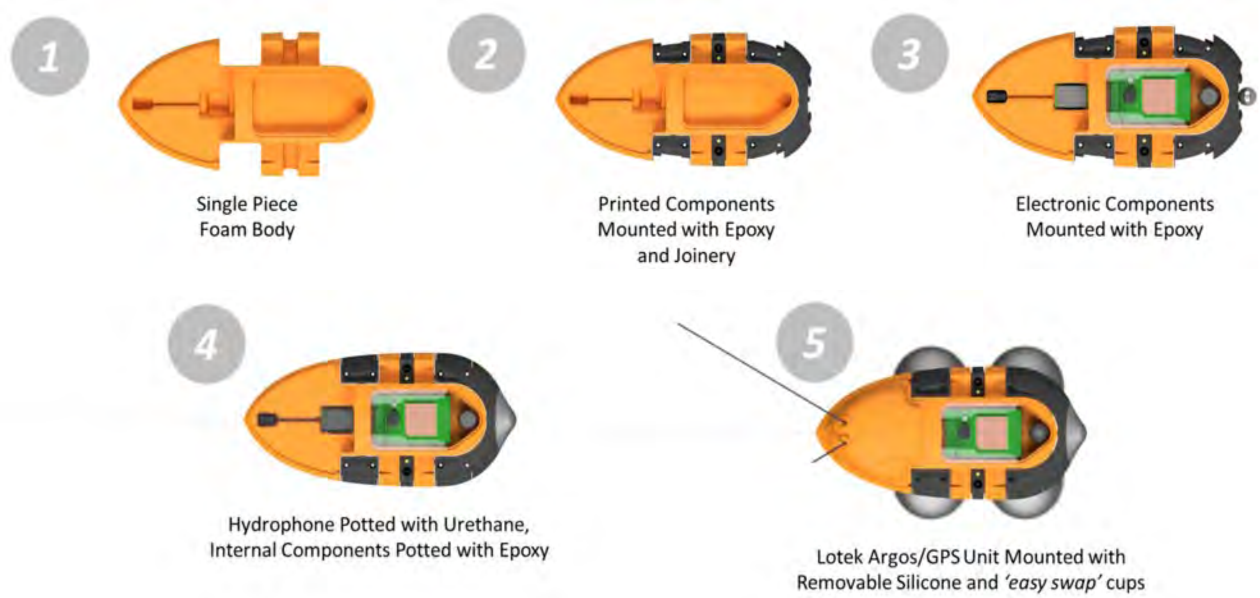


Figure 2: An illustration of the assembly process used to fabricate the tags.
1. The body of the tag is machined from a block of syntactic foam.
2. 3D printed components that integrate with the tag suction cups and position the hydrophone are then fixed to the foam using a combination of mechanical features and adhesives.
3. The electronics, sensors and battery are then added to the assembly.
4. Electronics/sensors are then encapsulated using urethane (hydrophone) and epoxy (electronics.
5. Finally, the suction cups and ARGOS tracking module are added to the assembly.

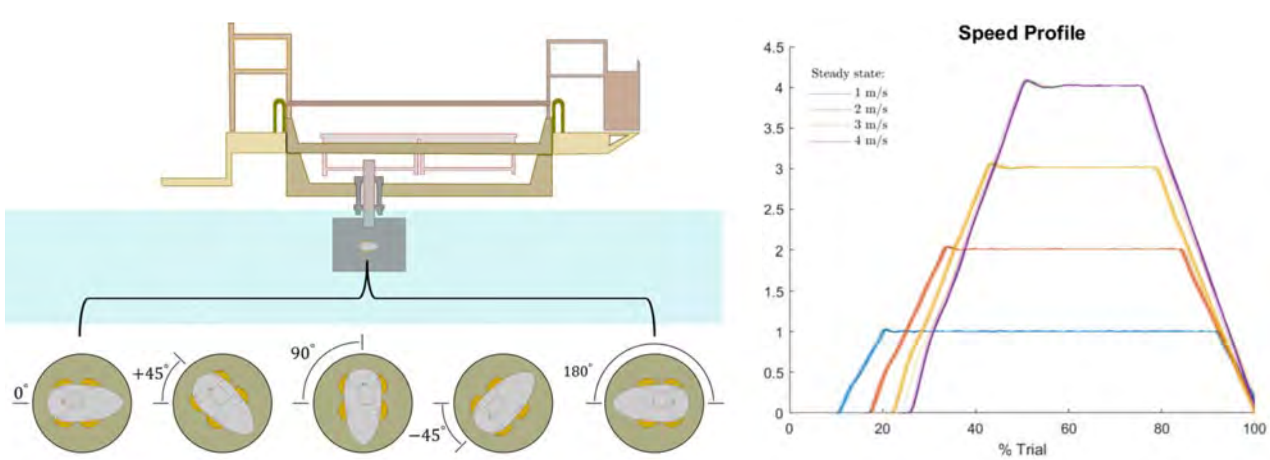


Figure 3: The test setup used to evaluate the performance of the suction cup attachment system under hydrodynamic loading (left). The tags were tested at speeds ranging from 1–4 m/s (right).

under real world conditions. Units will be field tested on a variety of species to capture the effects of different whale sizes and behaviors. Target species include humpback whales, deep diving sperm and pilot whales and, if available, beaked whales and Risso's dolphins. Any issues identified during the field testing will be documented and cataloged to facilitate necessary design changes.

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

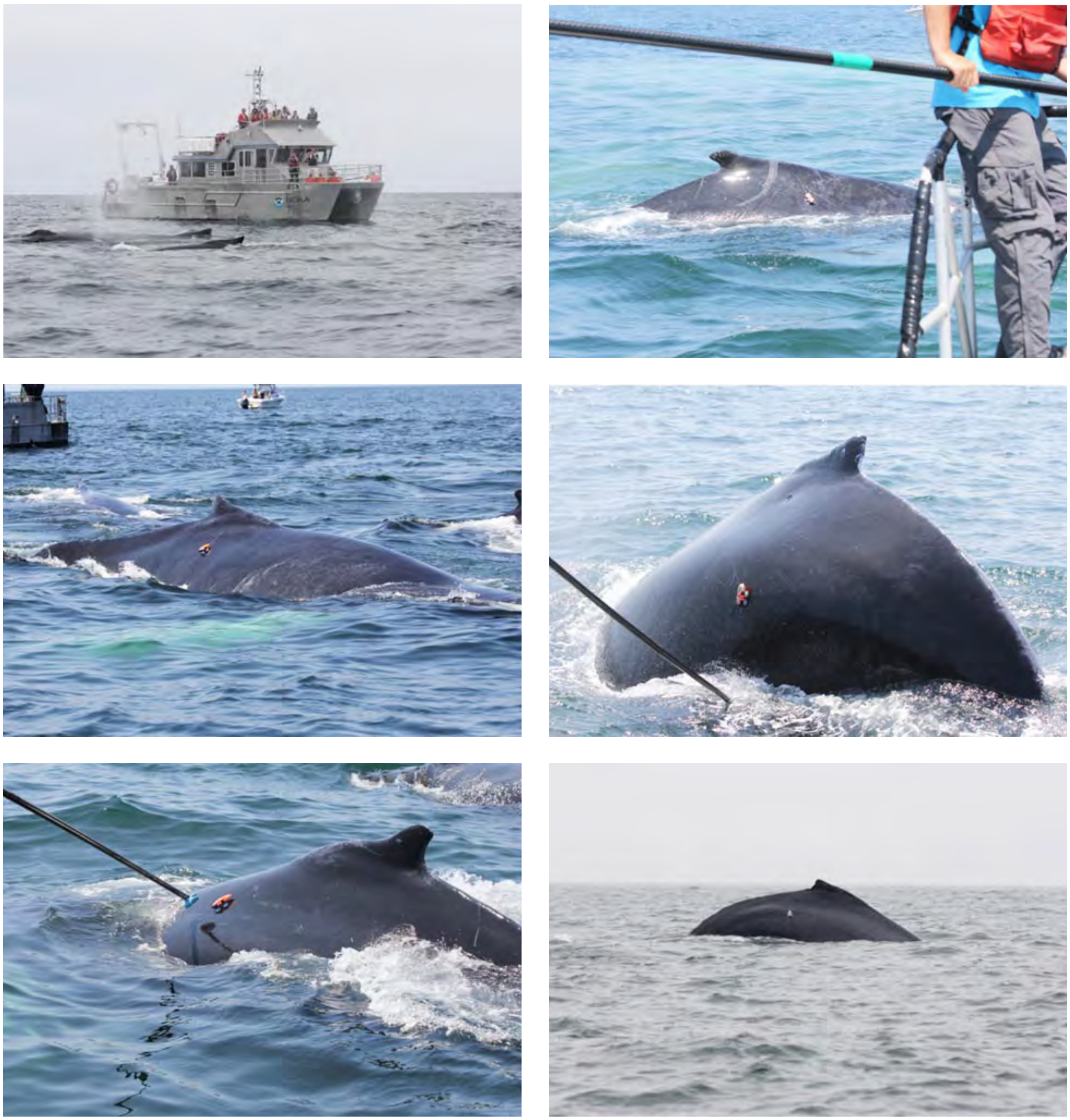


Figure 4: Tags were tested in the field during the summer of 2023 with collaborators at the Stellwagen Bank National Marine Sanctuary. All five tags fabricated during the first half of 2023 were deployed and recovered multiple times over the course of the field work, and all the instruments successfully recorded data from the animals.

into their field effort and create performance specifications for new tag features.

During 2023, the project team focused on designing and fabricating the new tag, followed by system testing both in the lab and field. During the fabrication process, the electronics were first assembled and tested using custom 3D printed structures, Figure 1. After the performance of the electronics was verified, the electronics and the mechanical components of the tag were assembled, Figure 2. The tag consists of a machined body made from syntactic foam, 3D printed structures to interface with the suction cups and position the hydrophone, and the electronics. The electronics were then encapsulated in epoxy and the hydrophone was encased in urethane. Five tags were assembled and tested ahead of field testing in the first half of 2023. Five additional sets of electronics were also assembled and tested during fall of 2023 and will be built into tags during winter 2024.

> 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 team then evaluated tag system performance in both the lab and the field. This included investigating 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, Figure 3. Multiple tag orientations relative to the flow were measured to simulate tag placements that might be expected in 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 tags were also tested in the field during the summer of 2023 with collaborators at the Stellwagen Bank National Marine Sanctuary, Figure 4. This field work enabled a holistic evaluation of the tagging system: deployment, attachment, release, recovery and measurement. All tags were successfully deployed and recovered during the field effort. Tags were deployed using a hand pole. Researchers collected data on initial tag placement, tag location and the behavioral state before and after tagging. 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.

The rigorously 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.

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.

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


Pilot whales.

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.
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 (DGA), 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 mixed-DTAG+ was used successfully in the 3S4 behavioral response trial in Norway demonstrating the benefit of this project to behavioral response studies.

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 (Project 64, page 79) in October 2023, demonstrating the benefit of this project to behavioral response studies.

Work planned for 2024 includes developing a robust tracking software (Capability 2) and redesigning the mixed-DTAG+ for use with a new DTAG core unit, while retaining the current GPS-ARGOS functions and video logger capabilities. Tag size in the new mixed-DTAG+ design will be guided by attachment durations seen in 2023. The average duration with the larger mixed-DTAG (11 hours) was longer than with the smaller integrated-DTAG (9 hours). Both the mixed-DTAG+ and the integrated DTAG will be field tested in 2024.

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 environmental 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).

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 sound. Project efforts are focused on both validating localization capabilities and establishing methods and guidelines for successful localization strategies.

The project will conduct three continuous recording (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 sparse array operation in scale, array density, usable frequency spectrum (sample rate), depth dependency and endurance.

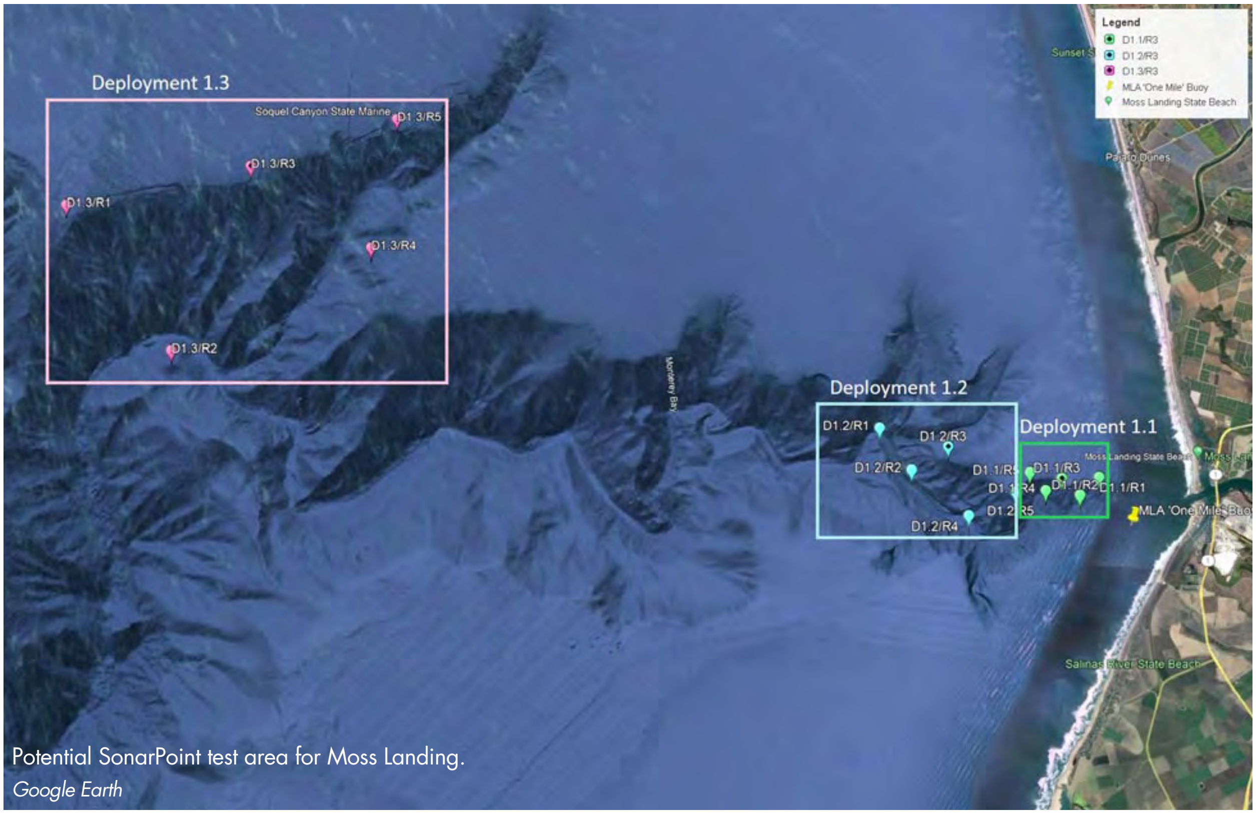
SonarPoint mooring string.
Desert Star Systems

Phase 1 deployments will be a subset of three week-long deployments that vary in depth and inter-recorder distance. In 2023 two of these deployments were completed: 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 is to evaluate how recorder spacing affects localization results to determine maximum recorder spacing. 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 analyzing 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 six recorders were recovered. Work is ongoing to address technical issues that will improve recovery success for future deployments, which include adding a duplicate acoustic release and adding in a satellite telemetry device to aid in recovery at the surface. Deployment 1.3 will occur in 2024.

The Phase 2 deployment is planned for later in 2024 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 twelve recorders will be deployed at 1,000–2,000 meters for a long-term deployment.

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.

Project analyses will continue to use PAMGuard (version 2.02.10) to process and annotate the datasets for all potential marine mammal calls. An initial exploration of the Group 3D Localizer for this task demonstrated that the tool (originally optimized for use with echolocating porpoises) might be less suitable for localization of large whale calls from sparse arrays. In 2024, the project will evaluate alternate localization methods, including tools used for large whale localization on the Pacific Missile Range Facility (PMRF) site. 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 continue to evaluate PAMGuard's Group 3D localizer for clicks when appropriate array (shorter distance) spacing is used for a subset of recorders in Deployment 2. The team will also evaluate other tools to identify optimal, objective approaches that incorporate automation where possible, to enable localization over the course of an entire acoustic event. These



Potential SonarPoint test area for Moss Landing.
Google Earth

Porpoise.
NOAA

tools can be compared to Desert Star Systems' approach to sound source localization to further evaluate and improve the processes.

Analyses and reporting will be conducted after each deployment, with a final report completed in 2025. 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.

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.

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 contributors: Elizabeth Ferguson (Ocean Science Analytics), Jeff Jacobson.

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 environmental 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, in order 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, standardized data management tools, and establishing metrics for reporting performance of data analysis methods.

There is one ongoing project and one new start project in this section.

The ongoing project is

1. Project 46—Tethys Capability Enhancements.

The new start project is

1. Project 66—Passive Acoustic Monitoring Access Network: Advancing Data Management and Cyberinfrastructure Solutions for a Big Data Problem.

MC3 Nicholas A. Russell

AE3 Lauren Duval

Ongoing Project

Tethys Capability Enhancements

Principal Investigator: Marie Roch
Project Status: Ongoing, 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 enhances 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 environmental 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 and became increasingly diverse, the need for additional enhancements to make the workbench more accessible became apparent.

This project is working to address the following key enhancements. Each is summarized below with its purpose and work completed thus far.

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

   This task was largely completed during 2021. There were two primary components targeted for upgrade. 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 and 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 are frequently reduced by up to two orders of magnitude. In addition, the project team implemented a caching scheme that reduces 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.

   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

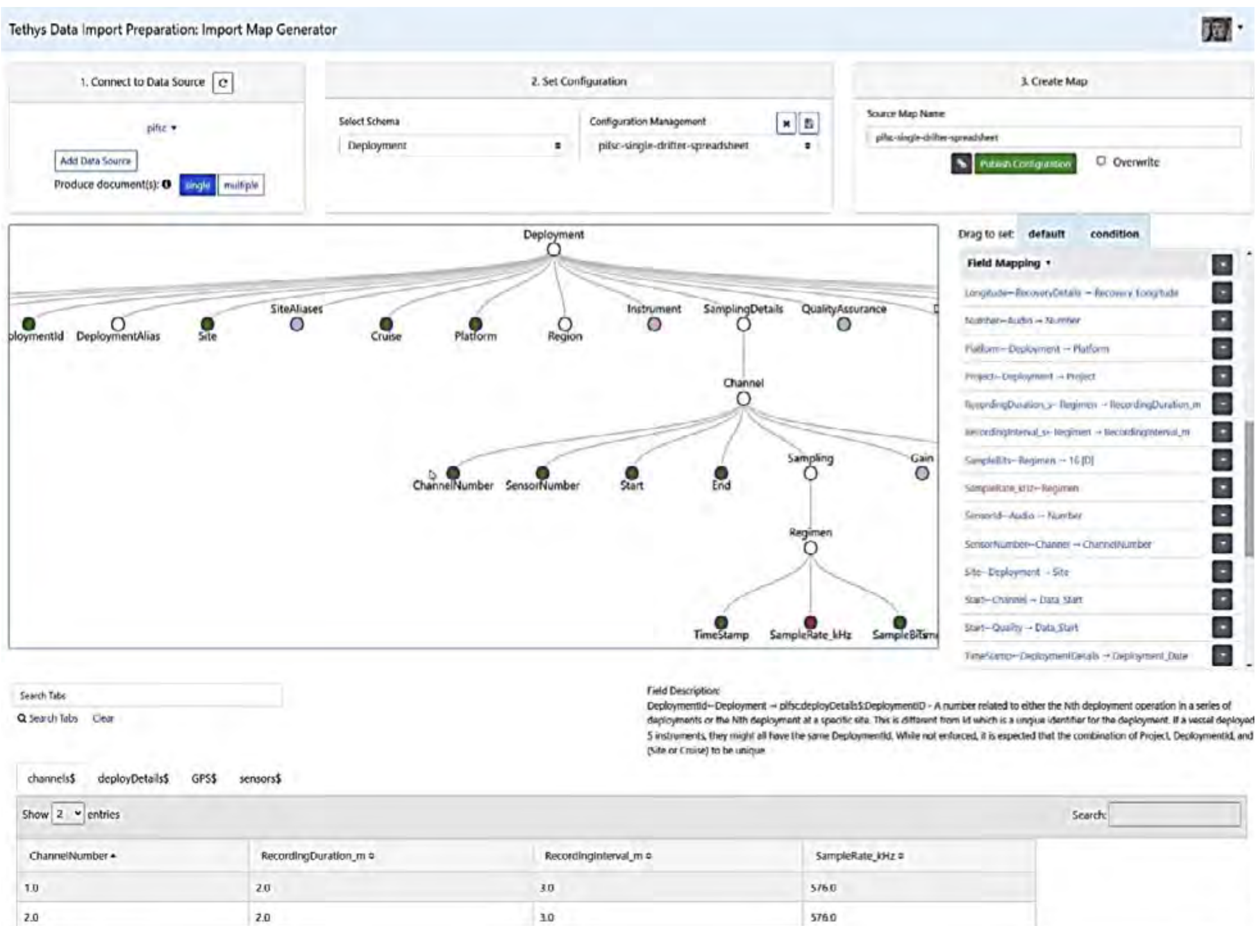


Figure 1: Web-based data import tool.
Users specify a sample data source from a database, spreadsheet, etc.
Tethys schemata are displayed in the upper panel and example data from the data source are displayed below, such as indicating which species detection effort has been made for by dragging SpeciesId to the column containing species information: "Species Code." A list of mapped fields is displayed on the right.
Once everything has been set, the configuration is published and can be used to import data.

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 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. 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 environmental 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 included requests for additional documentation (planned and underway) and easier data input, which is addressed with the data import interface described under 2, above.

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,

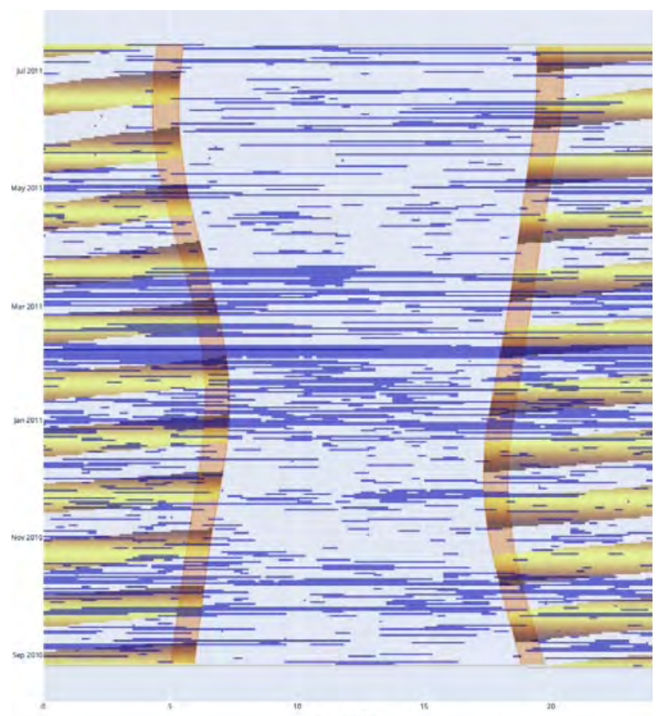


Figure 2: Occurrence of toothed whale echolocation (blue) on a daily cycle over a roughly one-year period near the Jacksonville Undersea Warfare Training Ranges (USWTR). Lunar illumination is shown in dark orange to bright yellow with bright yellow indicating more moonlight. The orange bands running from top to bottom on either side show nautical twilight (civil and astronomical twilight are also available). Earlier studies on the west coast using Tethys (Simonis et al. 2017; DOI 10.3354/meps12247) have shown that lunar illumination can affect foraging decisions in some species of dolphins, and one can see here that there is generally not as much echolocation during periods of bright lunar illumination.

to automatically publish data to Tethys. Large portions of this work will be trialed with a beta-user group in 2024. This work to integrate PAMGuard and Tethys will be beneficial to the Navy and the general user audience.

6. **Standards Committee**

   The project leads the Acoustical Society of America/American National Standards (ASA/ANSI) Institute working group (S3-SC1-WG7) for the standardized representation of bioacoustic data. This 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, which have been adopted by The National Center for Environmental Information as the data to be retained for its passive acoustic monitoring data archive. The committee has completed most of a how-to guide (recommended by ASA/ANSI) that motivates why and how the standard is used and began specification of the standard itself in 2023.

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

Tethys 3, the third version of the software, was released in 2023 and 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.

Work in 2024 will focus primarily on advancing the work of the standards group. In addition, the project will continue to integrate additional types of data into visualization tools and provide support to Tethys users.

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 environmental 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.

New Start Project

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

Principal Investigator: Carrie Wall
Project Status: New Start, 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 is piloting a community-focused national cyberinfrastructure capability for passive acoustic monitoring (PAM) data, technology and best practices. It intends to promote improved, scalable and sustainable accessibility to large quantities of PAM data and support applications for using the data for resource management and science. The project is jointly funded by the Navy (Living Marine Resources and Office of Naval Research), NOAA and BOEM.

The project will establish a Sound Cooperative (SoundCoop), also known as the Passive Acoustic Monitoring National Cyberinfrastructure Center, at the National Centers for Environmental Information (NCEI). The SoundCoop will promote the use of centralized assets where appropriate, leverage what has already been built towards a larger group of stakeholders and coordinate further development opportunities to avoid duplication and divergent products. It will work with NOAA's Data Management and Cyberinfrastructure (DMAC) system and enhance 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.

> This three-year effort will involve a wide range of interested parties and stepwise expansion.

The SoundCoop will work with prototype data from regional associations of the U.S. Integrated Ocean Observing System (IOOS®) to build their capacity to incorporate IOOS-supported PAM data collections. SoundCoop will also provide prototypes of multi-company offshore energy development data collections and continue work 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 than being a centralized repository for all the nation's PAM data collections. The connected repositories, operated with common infrastructure, will benefit bioacoustic research and management.

This three-year effort will involve a wide range of interested parties and stepwise expansion. There are four main objectives.

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 environmental data**
   Integrate environmental data to serve as a holistic PAM visualization platform.
4. **Develop a transition 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.

Efforts in 2023 focused on the NCEI Passive Acoustic Data Archive team activities, including creating a streamlined workflow to prepare datasets for submission to NCEI. Working closely with Dr. Kait Frasier (see LMR Project 60, page 92), the team defined and tested a workflow that significantly reduces the manual effort required to prepare data packages and creates content that meets the needs of the NCEI passive acoustic archive pipeline. The workflow efficiently organizes the metadata necessary to document each dataset. This semi-automated workflow is one of three workflows that are being shared with the passive acoustic community as the NCEI team continues to build processes that better meet the large data volume needs of its stakeholders.

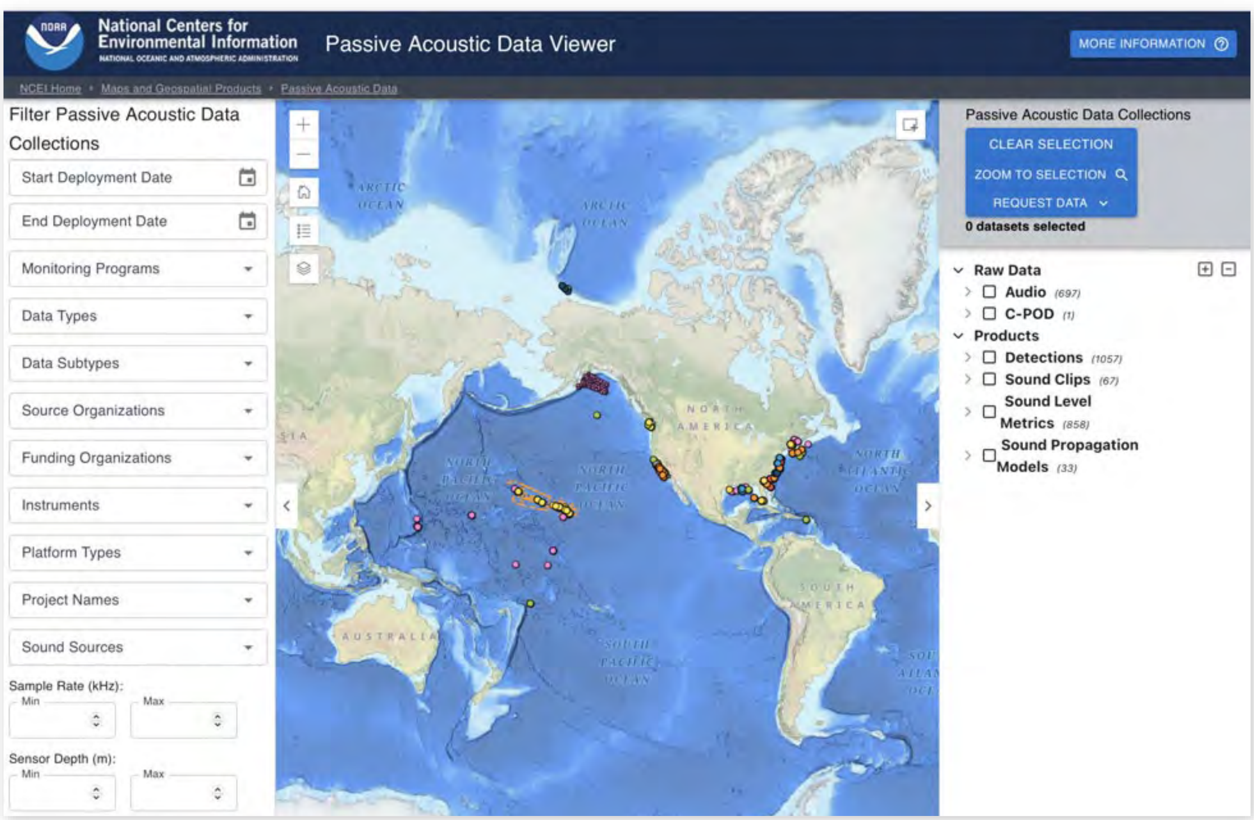


Figure 1: NCEI Passive Acoustic Data Archive Map Viewer for discovery and access to archived datasets.
www.ncei.noaa.gov/maps/passive-acoustic-data/

Through collaborative efforts with data providers, the NCEI Passive Acoustic Data Archive grew by 160 TB in 2023, reaching a total of 512 TB. Additional archive work completed in 2023 includes

- Revamped NCEI Passive Acoustic Data Archive Map Viewer (Figure 1)
- Revamped NCEI PassivePacker tool that includes new capability for capturing data products
- New content on the NCEI Passive Acoustic Data Archive project page on archive guidance (see 'Archive Resources' tab).

Archiving data will protect past Navy investments in passive acoustic monitoring and will preserve these time series and recordings.

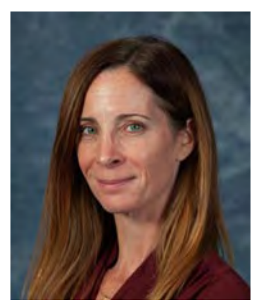
A beta version of the SoundCoop portal, developed by Axiom Data Science, was released. Portal users can interactively visualize a subset of hybrid millidecade results and integrate wind speed and wave height from nearby environmental sensors. Specifically, users can select which environmental sensor 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. An interactive online notebook capability—Jupyter Notebook—was developed as a means to share the workflow steps that enable any user to bring in a timeseries of sound level metrics in Network Common Data Form (NetCDF), pull nearby sensor data and visualize the results within the portal.

The Year 2 SoundCoop Workshop was held in Boulder, CO in October 2023. During the two-day workshop, the SoundCoop team shared the immense progress made 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 project will allow web access to the archived acoustic data and/or metadata records. The team will produce instructions and processes for future projects to use when organizing and preparing data for archiving.

Archiving data will protect past Navy investments in passive acoustic monitoring and will preserve these time series and recordings. The SoundCoop and NCEI archive will enable the data to be used in aggregate to quantify long-term changes in marine soundscapes. The effort will also help to evaluate and advance processes for large-scale open access passive acoustic data archiving and hosting at a national level.

About the Principal Investigator



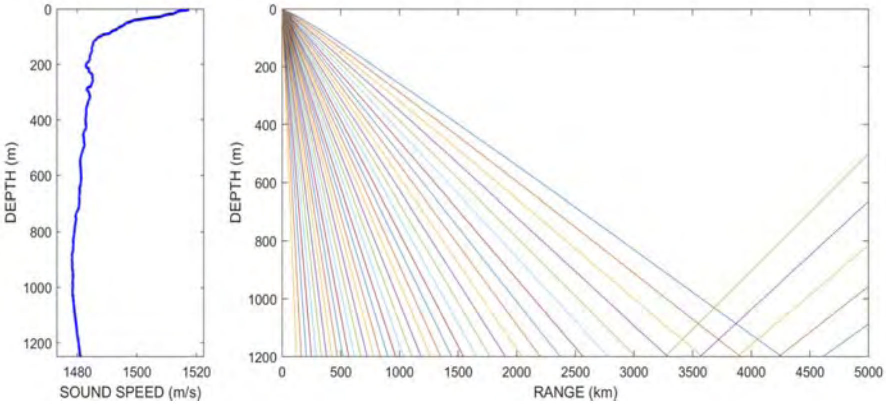
Carrie Wall is a research scientist at the University of Colorado, Cooperative Institute for Research in Environmental Sciences. She leads the passive acoustic and water column sonar archives at the NOAA National Centers for Environmental Information (NCEI). Dr. Wall holds a Ph.D. from the University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

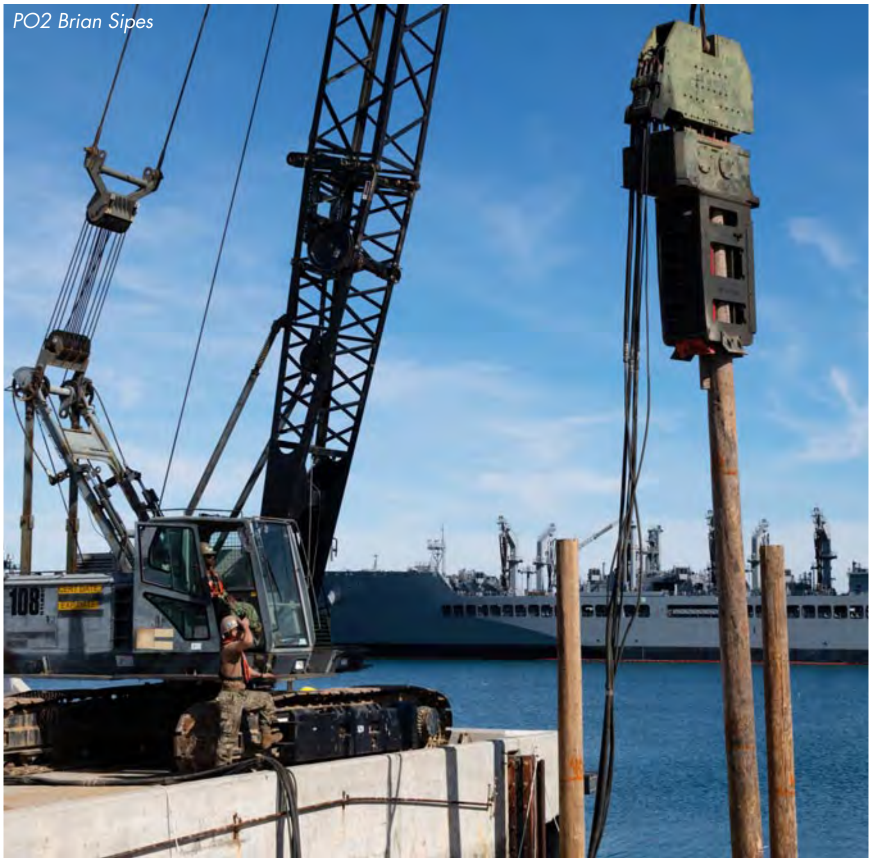
Key contributors: Leila Hatch (NOAA's Office of National Marine Sanctuaries), Robert Bochenek (Axiom Data Science), Sofie Van Parijs (NOAA's Northeast Fisheries Science Center).

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 the Navy's environmental compliance and permitting processes, or topics that do not squarely fall within the preceding categories.

The previous two projects in this investment area, Projects 35 and 48, were completed during 2023 (see Completed Projects section, page 21) and no new projects were started during 2023.





Completed Project 35 investigated underwater sound fields (ray theory/acoustic propagation diagram, top left) from explosive sources (top right). Potential future emergent topics could include effects of pile driving (bottom left) and invasive coral (bottom right).

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 two ongoing partnerships are

1. The Sonobuoy Liaison Working Group
2. 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. In 2023, LMR's request for 192 sonobuoys was fulfilled and the devices were sent to the University of California at San Diego's Scripps Institution of Oceanography.

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

Sonobuoys are inspected and loaded into an MH-60R Sea Hawk helicopter.
MC2 Aaron Lau

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.

Fact sheets for each of these projects are available on the LMR website under the SOST Partnership tab.

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—are being managed by the LMR program. Summaries of these two are presented in this report on pages 54 and 58, 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.

Humpback whale.

FORECAST

We look forward to even more accomplishments in 2024 and beyond. LMR will remain focused on meeting the Navy's need for research and technologies to sustain at-sea training and testing within environmental permit requirements. 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 our estimate of potential impacts. In collaboration with the Department of Defense Legacy Resource Management program and NAVFAC NW, we will be co-investing in a diet study of the ESA-listed marbled murrelet, a species that occurs in Navy training areas.

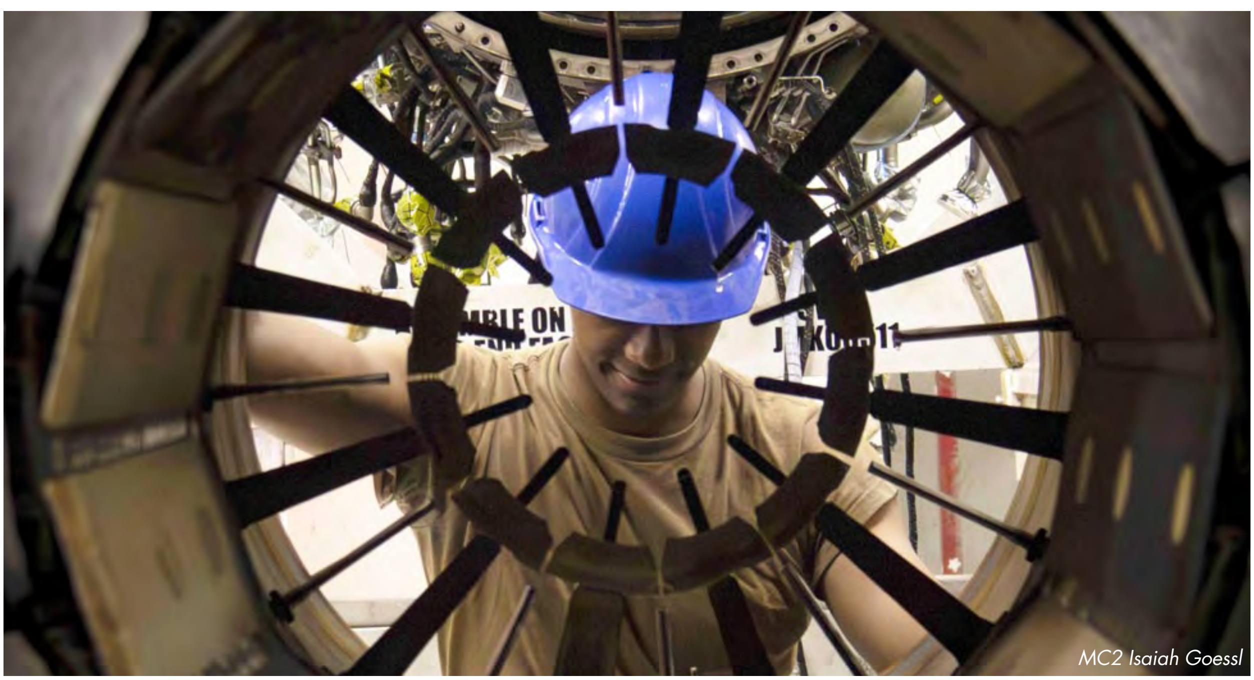
To enable us to proceed to Phase II of SURTASS LFA behavioral response study, we will be focused on identifying an appropriate sound source to support the work. Phase II field efforts are expected sometime in 2025.

Each of the projects being considered was identified through our ongoing discussions with Navy end users to identify priority research need topics. These discussions will continue in the year ahead to reveal new need topics for LMR investment in 2025 and beyond.

To that end, we value the sustained collaboration and partnerships with the Navy's other marine species programs—ONR 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.

During each of our ten years managing the LMR program, we have been 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 the Navy with priority research needs.

As always, this work ultimately is about our Sailors and our ability to maintain an effective and resilient Navy while being good stewards of the environment.



MC2 Isaiah Goessl

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Acronyms and Abbreviations

3S3/4 ....Sea Mammals and 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 ....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
BAA ....Broad Agency Announcement
BACI ....Before-After Control-Impact
BOEM ....Bureau of Ocean Energy Management
BRS ....Behavioral Response Study
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
CSEE ....Coordinated sonar exposure experiments
CT ....Computerized tomography
CTBTO IMS..............Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System
CW ....Continuous wave
DCL ....Detection, classification and localization
dB...Decibels
DTAG.....................................Digital acoustic recording tag
EDA ....Effective detection area
EIS.....................................Environmental Impact Statement
ESA ....Endangered Species Act
FM ....Frequency modulation
FSST...Full ship shock trial
GPS ....Global positioning system
HARP ....High frequency acoustic recording packages
HSTT ....Hawaii-Southern California Testing and Training Ranges
ICMP ....Integrated comprehensive monitoring plan
ITF-ONML ....Interagency Task Force on Ocean Noise and Marine Life
IPR ....In-progress Review
kHz...kilohertz
LFA ....Low Frequency Active sonar
LIMPET ....Low Impact Minimally Percutaneous External-electronics Transmitter
LMR..Living Marine Resources
LMRAC ....Living Marine Resources Advisory Committee
M3 ..................U.S. Navy's passive acoustic marine mammal monitoring data system
MARMAM ....Marine Mammals Research and Conservation Discussion (University of Victoria email list)
MFAS ....Mid-frequency active sonar
MMC....................................Marine Mammal Commission
MMP.........................U.S. Navy's Marine Mammal Program
MMPA.................................Marine Mammal Protection Act
MSM............U.S. Navy Marine Species Monitoring Program
NAEMO ....Navy Acoustic Effect 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
NEFSC ....Northeast Fisheries Science Center (NOAA)
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
OBS ....Ocean bottom seismometer
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
OPNAV N45 ....Chief of Naval Operations Energy and Environmental Readiness Division (predecessor to N4)
PAM ....Passive acoustic monitoring
PAM-DE ....PAM-based density estimation
PAS ....Pulsed active sonar
PCoD ....Population consequences of disturbance
PMRF ....Pacific Missile Range Facility
PTS ....Permanent threshold shift
RDT&E................Research, development, test and evaluation
SAM ....Sinusoidal amplitude modulated
SBIR ....Small Business Innovative Research
SCR ....Spatial capture recapture
SEL...Sound exposure levels
SMRT..................Sound and motion recording and telemetry
SOCAL ....Southern California range complex
SOST ITF-ONML ....Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life
SPL ....Sound pressure levels
SURTASS LFA ....Surveillance Towed Array Sensor System Low Frequency Active sonar systems
TRC...Technical Review Committee
TTS ....Temporary threshold shift
URL...Uniform resource locator
UUV ....Unmanned underwater vehicle
VHF..Very high frequency
WARP ....Whale Acoustics Reconnaissance Project
µCT..Computed microtomography

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