# LMR 2022

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

JULY 2023

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## LIVING MARINE RESOURCES PROGRAM
## ANNUAL REPORT

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*Marine mammal photos that do not include a credit/permit number are from stock photo services.*
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# INSIGHTS

Welcome to our annual update on the Living Marine Resources (LMR) Program. This report is a capsule-view of the valuable work performed by all LMR participants to support the Navy's ability to train, test and be mission-ready. In the Program Overview section (starting on page 8) we offer a brief history of the program, summarize how the LMR program supports the Navy's at-sea environmental compliance process, outline how we work with other Navy programs and highlight collaborations with federal agencies.


Program Manager Anu Kumar and Deputy Program Manager Mandy Shoemaker.

The Program Portfolio section (starting on page 22) includes background and updates on our many technical projects. In 2022, the LMR program was managing 32 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 32 projects include eight new projects, 19 ongoing projects and five projects that were completed during 2022.

Products from the five completed projects are being transitioned to the end users. The completed projects and results include the Auk hearing study project (Project 22), which provided the Navy with important hearing data to evaluate potential impacts to protected seabirds. Projects 23 and 30 demonstrated a new medium tag


*MC2 Justin McTaggart*

technology and collected important data on behavioral response to both coordinated and opportunistic sonar events. The DenMod project (Project 31) led a successful interagency workgroup to address several challenges affecting marine mammal density modeling. The Sonar Project (Project 34) helped to standardize the nomenclature used to describe sonar and to develop a new sonar detector. The project also recommended best practices to automate analysis.

A list of publications since 2013 is available under the Publications tab on our website, exwc.navfac.navy.mil/LMR.

Results from all these current and past projects continue to contribute to the scientific literature that provides critical, well-founded scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) environmental planners, regulators, scientists and other stakeholders. Citations for 2022 publications are listed in the Publications section of this report (page 122). A list of publications since 2013 is available on our website (exwc.navfac.navy.mil/LMR) under the Publications tab.

We are proud to note our successes meeting the Navy's rigorous financial performance requirements while ensuring high quality work within each project. The projects in LMR's diverse technical portfolio are performed by principal investigators from universities, research institutions, nonprofit research groups and foundations, private companies, and Navy research centers, each

*MC2 Aaron Lau*


MC2 Sawyer Connally

with its own contract procedures. Despite some challenges posed by this process, meeting the financial requirements enables LMR to maintain a successful and healthy program, with the potential to grow in the future.

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

In addition to carefully managing the LMR-funded efforts, we collaborate with other federal agencies to leverage marine science expertise and funding sources to mutual benefit. These efforts have leveraged over $9 million of external funding. See the Coordination/Collaboration section on page 18 for more details.

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
- Demonstrating and validating basic research projects that are ready for applied research investment
- 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.

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.

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.

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 11.) 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.

> The highest priority is to transition successful products to the Navy's at-sea environmental compliance process.

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 cooperation, leveraging resources across related programs, and optimizing limited funding resources (see the "Coordination/Collaboration with Other Programs, Agencies and Research Institutions" section on page 18 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).

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

1. The Office of Naval Research Marine Mammals and Biology program (ONR MMB)
2. The LMR program
3. 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 14).

MC2 Joseph Calabrese

## 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 speciess.
- 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.

> 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.

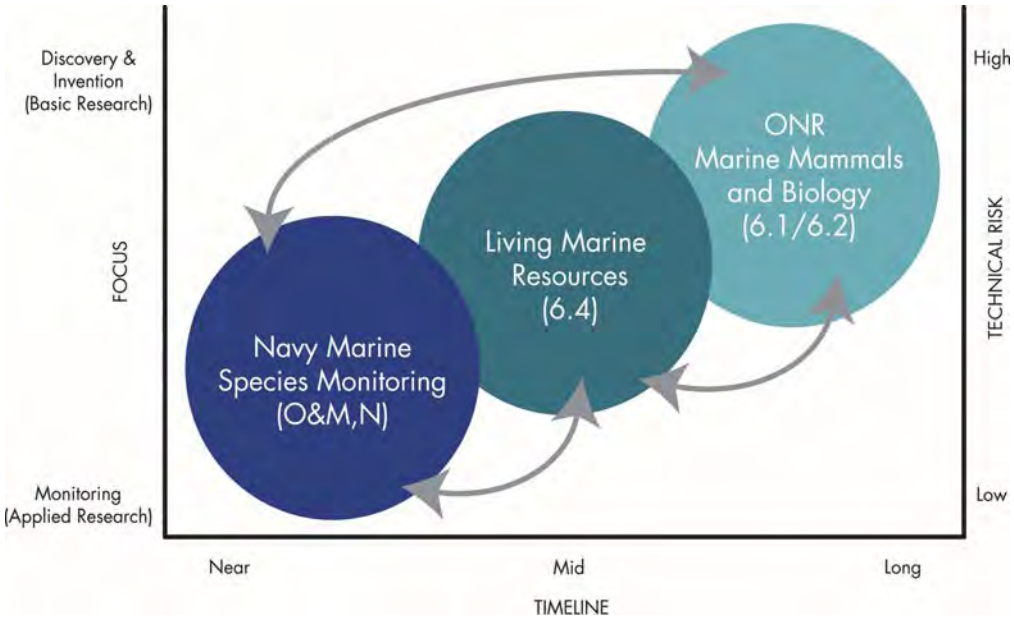
The LMR efforts are critical to ensuring an efficient process for obtaining the most effective tools and reliable data to support environmental compliance. By providing a centralized program to address the Navy end users' stated needs, LMR provides a clear path for getting solutions and results to those 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 above 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. Case studies in previous annual reports (2018 and 2020) summarized examples of this process.

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.

*MC3 Joshua Martinez*

## 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 starts.

## 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


MC2 Jeremy Boan

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.

   *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

Blue whale.
*Cascadia Research Collective*

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.

## 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 at: exwc.navfac.navy.mil/lmr. Non-Navy person-

nel 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.

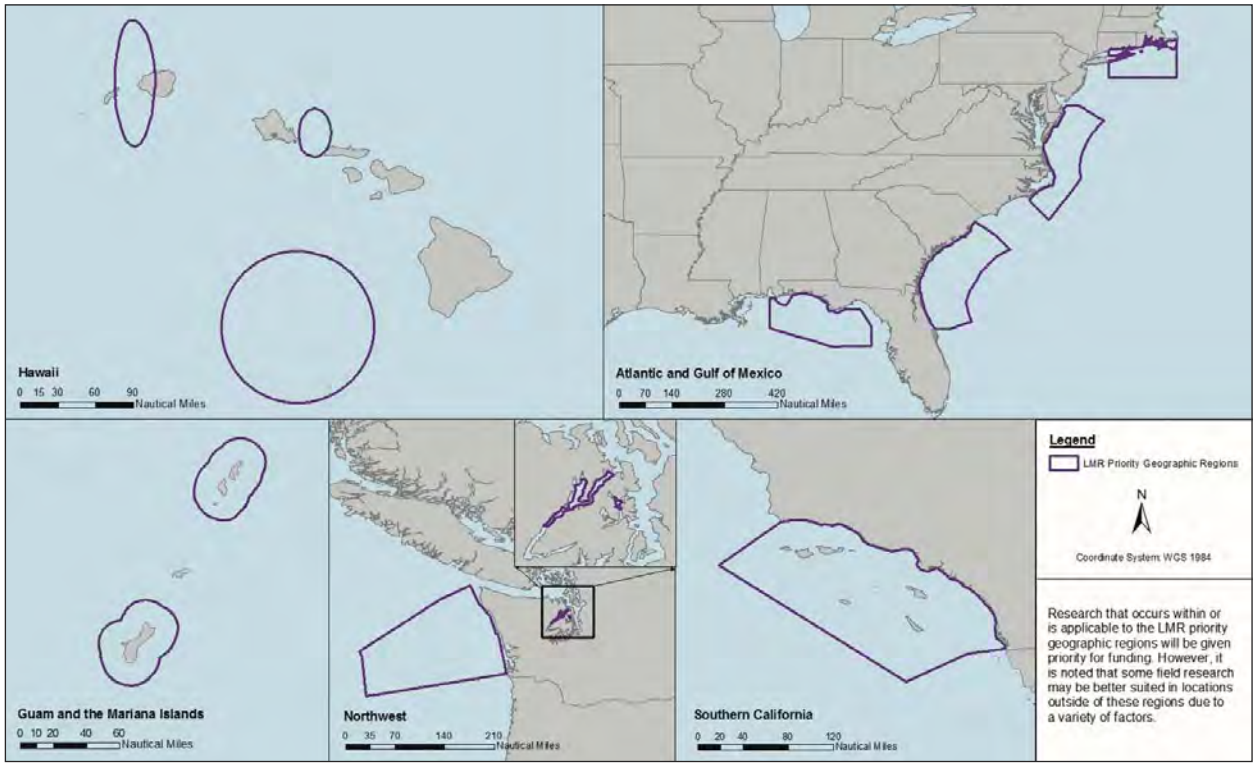
## Priority Species and Geographic Regions

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




LMR priority geographic 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 pre-proposals. 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 48 and 51, respectively.

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
3. EOM Offshore.

After the completion of Phase I, Triton Systems was selected for a Phase II, which went through Fall of 2022. 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 the end of 2023, will include integrated systems field testing. If results are successful, the LMR program will determine whether to proceed with funding a Phase III effort.

Since 2014, LMR has managed ten projects that involve coordination with outside organizations. These projects have leveraged over $9 million dollars in external funding. Of this leveraged funding, forty-three percent ($3.9 million) has come from other Navy programs (e.g., ONR and SBIR) and the other fifty-seven percent ($5.1 million) has come from outside the Navy. In addition to funding benefits, these projects build a knowl-


MC2 Samantha Oblander

edge 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.

> LMR projects have leveraged over $9 million in external funding.

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 out of research and 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.

## Quarterly Newsletters

The LMR program issues a quarterly 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 2022, the spreadsheet list included 147 publications, beginning in 2013 from the earlier Marine Mammal Research program, which preceded the LMR program's establishment in 2014. While the list focuses on publications resulting from Navy LMR funding, it also includes publications not specifically funded by the LMR program but that acknowledged use of data, methodology or technology developed with funding from LMR.

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

The spreadsheet is updated 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's website address is exwc.navfac.navy.mil/lmr.

## 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 pre-proposal solicitation is issued, and provides information needed for pre-proposal submission.

# PORTFOLIO

# Completed Projects

Five projects were completed during 2022 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 22—Hearing and Estimated Noise Impacts in Three Species of Auk: Implications for the Marbled Murrelet
2. Project 23—Cuvier's Beaked Whale and Fin Whale Behavior During Military Sonar Operations: Using Medium-term Tag Technology to Develop Empirical Risk Functions
3. Project 30—Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar
4. Project 31—DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling
5. Project 34—Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar.

## LMR Projects

### Hearing and Estimated Acoustic Impacts in Three Species of Auk: Implications for the Marbled Murrelet

**Principal Investigator: Aran Mooney**
**Project Status: Completed, Project 22**

#### 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

Some Navy readiness activities occur in areas that overlap with the natural habitat of the marbled murrelet (*Brachyramphus marmoratus*), a member of the Auk (or Alcidae) family that is listed as threatened under the Endangered Species Act (ESA) in Washington, Oregon and California, and state-listed as endangered in California. Potential effects from sound-producing activities might include auditory impacts such as temporary and permanent hearing threshold shifts as well as behavioral effects. Because basic data on the hearing of marbled murrelets or any other Auk species have been lacking, current impact assessments and mitigation measures for birds are based on fish or marine mammal data, which may be resulting in unrealistic mitigation zones and assessments of effect. Therefore, the Navy needs data to improve impact assessments and validate associated mitigation zones related to birds.

At the time this project was funded in 2016, there were no basic data on the hearing capabilities of marbled murrelets or any other Auk species, which limited what was known about the fre-


Common murres.

quencies or sound levels that would induce effects. The project team, working in Iceland, Denmark and Alaska, pursued multiple methods to test Auk hearing.

Over the course of the project, researchers conducted both auditory evoked potential (AEP) methods and behavioral audiometric methods. Data collection efforts included in-air AEP tests, in-air behavioral audiometry tests and underwater behavioral audiometry tests. These tests allowed researchers to compare AEP and behavioral audiometric methods and to compare in-air and underwater measurements. In addition to AEP and behavioral audiometry testing, the team also completed micro computed tomography (micro-CT) scans to define anatomical differences and similarities among the species.

Between 2017 and 2020, the team successfully completed field-collected in-air AEPs on puffins and common murres in northwestern Iceland and marbled murrelets in Alaska (where the murrelets are not listed as endangered). These experiments followed the same AEP collection method on all three species, which supports audiogram comparisons among the three. The murre and murrelet audiograms are quite similar in terms of their overall sensitivity whereas the puffin is consistently more sensitive by about 10 dB across the majority of the auditory bandwidth.

The project also conducted behavioral hearing tests, both in-air and underwater, with common murres. With significant effort and persistence, the team trained birds for sound-sensitivity tests. They collected underwater behavioral hearing data, revealing that these birds do hear underwater, which previously was unknown. Through hundreds of in-air and underwater behavioral audiogram testing sessions of the trained common murres, the team worked to resolve the behavioral responses and evaluate their sound-sensitivity and perception. The common murres showed sensitive in-air hearing, supporting the field-based physiological tests. Underwater, the animals had difficulty with the conditioned underwater tasks, particularly at lower sound levels, implying that while sound-sensitive, they may not readily utilize underwater acoustic cues.

Micro-CT scanning and anatomical modeling efforts have helped to provide initial measures of the auditory structures and comparative analyses. These assessments suggest that hearing anatomy may have some small adaptations for deep diving

but the structures are largely similar across Auks, underscoring the ability to compare these data.

Work during 2022 focused on completing data analyses and preparing manuscripts for publication. By the end of the year the project had four published articles, one in press, one in review and several more in progress. (See Publications sidebar for citations)

The project has provided new approaches for studying Auk hearing and new data to support refining acoustic criteria for the marbled murrelet.

The project has provided new approaches for studying Auk hearing and new data to support refining acoustic criteria for the marbled murrelet. In addition to audiograms for murres, puffins and marbled murrelets, the project has provided new methods for conducting AEPs on wild birds in the field as well as insights on conducting behavioral testing of seabird hearing.

These results will allow the Navy to improve the assessment of potential effects of training and testing activities on Auk species, including marbled murrelets, and will contribute to more appropriate mitigation zones.

### About the Principal Investigator

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.

*Key collaborators: Marianne Rasmussen (University of Iceland), Magnus Wahlberg (University of Southern Denmark).*

### Publications


Smith, A.B., Kissling, M., Capuano, A.M., Lewis, S.B. and Mooney, T.A. (In press). Aerial hearing thresholds and ecoacoustics of a threatened pursuit-diving seabird, the marbled murrelet (*Brachyramphus marmoratus*). *Endangered Species Research*.

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Mooney, T.A., Smith, A., Larsen, O.N., Hansen, K.A., Wahlberg, M. and Rasmussen, M.H. (2019). Field-based hearing measurements of two seabird species. *Journal of Experimental Biology*, 222(4):jeb190710. DOI 10.1242/jeb.190710.

Mooney, T.A., Smith, A., Hansen, K.A., Larsen, O.N., Wahlberg, M. and Rasmussen, M. (2019). Birds of a feather: Hearing and potential noise impacts in puffins (*Fratercula arctica*). *Proceedings of Meetings on Acoustics*, 37(1):010004. DOI 10.1121/2.0001037.

## Cuvier's Beaked Whale and Fin Whale Behavior During Military Sonar Operations: Using Medium-term Tag Technology to Develop Empirical Risk Functions

**Principal Investigators:**
**Greg Schorr, Erin Falcone**
**Project Status: Completed, Project 23**

### NEED

**N-0102-16: Behavioral Response Research to Study the Effects of Sound on Marine Mammals**

The Navy needs more information on aspects of marine mammal behavior in response to Navy training and testing activities. Two related topics within this need are: 1) research on how different variables may impact the behavioral response of the animal, including range between the source and animal during exposure, frequency range of the source, and behavioral state of the animal during exposure and 2) demonstration of tags that can collect high-fidelity animal movement and behavioral responses over a longer-term duration (preferably weeks to months). The Navy needs improved behavioral response data in order to update risk threshold criteria and reduce the uncertainty of the current impact assessments.

### PROJECT

This project collected fine-scale animal behavior data during Navy activities involving the use of mid-frequency active sonar (MFAS) from multiple platforms across a range of distances. The project team deployed longer-duration, high-resolution behavior recording tags within an opportunistic exposure (OE) approach to document the behavior of two species—Cuvier's beaked whales (*Ziphius cavirostris*) and ESA-listed fin whales (*Balaenoptera physalus*)—before, during and after actual Navy exercises.

The OE approach involves tagging animals in areas where Navy activities occur; the tags then collect data on how the animals behave when exposed to activities that happen to take place near the animal. Animal behavioral data are collected without needing to schedule with the Navy platforms (e.g., ships, helicopters), which enables recording a larger sample of real-world exposures. The team used data archives from the Marine Mammal Monitoring on Navy Ranges (M3R) system, automated sonar detector outputs and a ship tracking database to confirm acoustic inputs from Navy activities.

This project worked closely with another LMR-funded project, Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar (Project 30, page 30). That project augmented the response data collection by using coordinated sonar exposure experiments.

Field efforts in Southern California began in 2017, where the team deployed the first Lander2 tag on a fin whale that was then subsequently exposed to helicopter dipping sonar. The Lander2 tag captures high-resolution diving, movement and location data, but does not record acoustics. During 2018, the project team completed five productive field efforts, including successfully collecting opportunistic exposure data from three Lander2 tags deployed on Cuvier's beaked whales. The team also began developing the processes required to combine animal movements and diving behavior from tags, tracks from ships and helicopters participating in exercises, and archived acoustic data from the range hydrophones and/or acoustic recording tags within a unified framework.

Field tagging efforts and data analyses continued during 2019. Two more Lander2 tags were deployed (one on a Cuvier's beaked whale and one on a fin whale) along with five next-generation Sound and Motion Recording and Telemetry

(SMRT) tags (all on Cuvier's beaked whales). The SMRT tags record acoustics for up to eight days at 96 kHz, in addition to depth, 3-axis accelerometer and magnetometer, and GPS locations for the duration of attachment. All seven of the whales tagged in 2019 were exposed to operational Navy sonar, including both ship and helicopter sonar at a range of distances and while in a variety of behavioral states.

The team also worked with both the Naval Postgraduate School and NAEMO (Navy Acoustic Effects Model) analysts to model sonar received level estimates from the 2018 tag data, which did not include direct acoustic measurements. An added data analysis effort during 2019 focused on using the fine-scale movement and accelerometry data from the Lander2 tags deployed in 2017 and 2018 to evaluate the potential to identify foraging activity when acoustic data are not available.

After the first field effort of 2020, during which one SMRT tag was successfully deployed on a Cuvier's beaked whale, all subsequent field efforts planned for 2020 and part of 2021 were canceled due to COVID-19 travel and work restrictions. The project team then redirected efforts to more detailed data analyses. While the original plan included a basic acoustic audit of SMRT tag data to capture animal sounds (e.g., click start/end times) and sonar pings, a more detailed audit was conducted that included differentiation of tagged animal versus conspecific animal clicks, buzz (prey capture attempt) identification, impulsive events and other anthropogenic sounds. The results of these detailed audits helped to advance cue rate assessments and address some basic biology questions for Cuvier's beaked whales that are relevant to this and other Navy research. The team also progressed on accurately identifying foraging dives without acoustic data (e.g., from Lander2 tags or SMRT tags when acoustics had turned off) by analyzing the accelerometer data from SMRT tags along with the SMRT acoustic data. The 2020/2021 analysis period also provided time to

Cuvier's beaked whale.
*Gregory S. Schorr, permit 16111*

identify suitable cetacean response models for processing extensive, multi-stream data sets earlier than planned.

During 2021, the project team resumed tagging efforts, continued data analyses and pursued statistical model refinements. An additional eight tags were deployed during the year (five on Cuvier's beaked whales and three on fin whales). One additional tagging event was added in January 2022.

Project tag deployments by the close of 2022 totaled 21, including both Lander2 and SMRT tags. The resulting data have been used to model behavior (e.g., dive cycles, foraging effort, displacement) as a function of received levels of, and distance to, MFAS.

During 2022 the team completed tag audits and sonar data compilation, and focused on integrating all data into the selected analytical framework. The project's sonar response model supported both fine and coarse time scale analyses. The fine scale framework employed a hierarchical hidden Markov model approach, which applied to data from SMRT tags with acoustics. The team also analyzed motion tag data against the motion and acoustics data to estimate behavior when acoustic data are not available. An article summarizing the detection of foraging dives without acoustics was published in 2022 (see Publications sidebar for citation). Two publications in 2022, written by other researchers, employed data from this project. Several additional manuscripts using project data are in preparation. Multiple previous publications reporting on data collected by this project are listed in the Publications sidebar.

This project contributed valuable high-resolution behavioral data, including accurate movements surrounding real MFAS exposure, for beaked and fin whales. This includes responses to novel sonar signal types, such as Continuous Active Sonar (CAS), and responses to explosives or other impulsive sounds. A total of three CAS exposures were captured (one exposure was captured by two different animals), representing the first time an animal-borne tag on a Cuvier's beaked whale captured CAS exposures. For the CAS exposure with the highest received level (131 dB re 1µPa RMS), there was a 17.7-hour foraging disruption, the longest recorded out of our entire data set of more than 5,700 hours of tag data.

While responses varied between individuals and exposures, the preliminary model results from the SMRT tags with concurrent acoustic recordings suggest that during sonar exposures, whales are more likely to transition to a 'response' state. Most notably, this means that during exposure whales are more likely to transition to, or remain in, a high-energy state that does not include foraging.

The final project report and publications are providing results that are directly applicable to risk function development for Navy compliance efforts.

This project also provides collateral data, such as photographs and cue rate data, to related studies. Data analysis methods developed for use with dart-attached archival tags are being contributed to an existing online repository (animaltags.org), along with documentation and instructional vignettes. These methods are readily transferrable to other species and geographic regions where the Navy needs similar data to estimate the effects of its activities. The final project report and publications are providing results that are directly applicable to risk function development for Navy compliance efforts.

### About the Principal Investigators

Greg Schorr, a research biologist at the Foundation for Marine Ecology & 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.

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

## Publications through 2022


Sweeney, D., Schorr, G., Falcone, E., Rone, B., Andrews, R., Coates, S., Watwood, S., DeRuiter, S., Johnson, M. and Moretti, D. (2022). Cuvier's beaked whale foraging dives identified via machine learning using depth and triaxial acceleration. *Marine Ecology Progress Series*, 692:195-208. DOI 10.3354/meps14068.

Coomber, F.G., Falcone, E.A., Keene, E.L., Cárdenas-Hinojosa, G., Huerta-Patiño, R. and Rosso, M. (2022). Multi-regional comparison of scarring and pigmentation patterns in Cuvier's beaked whales. *Mammalian Biology*, 102:733-750. DOI 10.1007/s42991-022-00226-6.

Curtis, K.A., Falcone, E.A., Schorr, G.S., Moore, J.E., Moretti, D.J., Barlow, J. and Keene, E. (2020). Abundance, survival, and annual rate of change of Cuvier's beaked whales (*Ziphius cavirostris*) on a Navy sonar range. *Marine Mammal Science*, 37(2):399-419. DOI 10.1111/mms.12747.

Barlow, J., Schorr, G.S., Falcone, E.A. and Moretti, D. (2020). Variation in dive behavior of Cuvier's beaked whales with seafloor depth, time-of-day, and lunar illumination. *Marine Ecology Progress Series*, 644:199-214. DOI 10.3354/meps13350.


## Publications acknowledging data


Falcone, E.A., Keene, E.L., Keen, E.M., Barlow, J., Stewart, J., Cheeseman, T., Hayslip, C. and Palacios, D.M. (2022). Movements and residency of fin whales (*Balaenoptera physalus*) in the California Current System. *Mammalian Biology*, 102:1445-1462. DOI 10.1007/s42991-022-00298-4.

Jones-Todd, C.M., Pirotta, E., Durban, J.W., Claridge, D.E., Baird, R.W., Falcone, E.A. Schorr, G.S., Watwood, S.L. and Thomas, L. (2022). Discrete-space continuous-time models of marine mammal exposure to Navy sonar. *Ecological Applications*, 32(1):e02475. DOI 10.1002/eap.2475.

Barlow, J., Fregosi, S., Thomas, L., Harris, D. and Griffiths, E.T. (2021). Acoustic detection range and population density of Cuvier's beaked whales estimated from near-surface hydrophones. *The Journal of the Acoustical Society of America*, 149(1):111. DOI 10.1121/10.0002881.

Keen, E.M., Scales, K.L., Rone, B.K., Hazen, E.L., Falcone, E.A. and Schorr, G.S. (2019). Night and day: Diel differences in ship strike risk for fin whales (*Balaenoptera physalus*) in the California Current system. *Frontiers in Marine Science*, 6:730. DOI 10.3389/fmars.2019.00730.

## Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar

**Principal Investigator: Stephanie Watwood**
**Project Status: Completed, Project 30**

### NEED

**N-0135-17: Understanding the Range to Effect on the Behavioral Response of Marine Mammals from Sonar Exposure**

Results from previous behavioral response studies indicate that the context in which marine mammals experience exposure to acoustic sources could affect their response. In particular, the Navy needs information on how the range (distance) of the sound source to the animal may affect behavioral response. Behavioral response data from a variety of operational Navy sources such as hull-mounted sonar, dipping sonar, and other types are needed. The Navy needs improved behavioral response data in order to update risk threshold criteria and reduce the uncertainty of the current impact assessments.

### PROJECT

While data from several Navy-funded projects have documented cetacean responses, particularly by Cuvier's and Blainville's beaked whales, to mid-frequency active sonar (MFAS) from ships, data from some field efforts have raised questions about whether those responses were based on received levels alone or other factors. Some data indicate that a given animal can react differently to similar exposures (i.e., within the same range of received sound levels) depending on the sonar source itself and the distance the animal is from the source.

MH-60R Sea Hawk helicopter deploying a sonar dipping buoy.
*MC3 Walter M. Wayman*

This project conducted coordinated sonar exposure experiments (CSEE) using a lower source level sonar than hull-mounted ship sonar, deployed at multiple, pre-defined distances from tagged animals. The effort is closely coordinated with another LMR-funded project that used high-resolution, medium-duration monitoring tags to record behavioral responses of Cuvier's beaked whales and fin whales during Navy training and testing activities. That project (Project 23, page 26)

employed an opportunistic exposure (OE) approach, in which animals were tagged prior to Navy training activities in order to document the behavior of animals before, during and after the actual Navy exercises. The data from the CSEEs are augmenting the OE data, with the intent to fill in exposures at ranges not captured in the OE data.

The CSEE project included both exposure and control scenarios for helicopter-deployed dipping sonar, which is frequently used during training on the Southern California Antisubmarine Warfare Range (SOAR). Standard mitigation measures were conducted prior to all CSEEs, as outlined in the Navy's Letter of Authorization under the Marine Mammal Protection Act.

The tagging team from Project 23 deployed the high-resolution, behavior recording tags on whales on SOAR to collect animal response data. The two species of particular interest were Cuvier's beaked whales (*Ziphius cavirostris*) and ESA-listed fin whales (*Balaenoptera physalus*). After successfully tagging, the team coordinated with the helicopter crews that work with dipping sonar. Using near real-time tag location data, the team proposed a dipping location for the helicopter crew.

During 2018, data were collected in coordination with three helicopter dips. These were for two tagged Cuvier's beaked whales and included two exposure dips and one silent dip. This type of coordination enabled more finely detailed data on the sonar sources regarding time, distance and the source characteristics.

In 2019, the teams completed three CSEEs with helicopter dipping sonar on Cuvier's beaked whales, filling in missing exposure distances collected from the opportunistic approach taken in Project 23. Additionally, one control CSEE was conducted on a tagged fin whale, just prior to planned active dips associated with a training exercise. Data analysis efforts included reviewing Marine Mammal Monitoring on Ranges (M3R) archive files for the presence of sonar during the tagging periods of 2017-2019. The team also began comparing received levels, using multiple models, to assess variance between modeling approaches and compare that with received levels from the acoustic tags. The coordination with the dipping helicopters in these cases provided a precise source location and depth, which combined with the Fastloc® GPS locations from the tagged whale makes this data set ideal for conducting this type of test.

> The project demonstrated successful coordination with the Navy helicopter squadron that made possible the results that will allow the Navy to improve impact assessments.

Additional CSEEs planned during 2020 were canceled due to COVID-19 travel and work restrictions. The team pivoted its focus to detailed data analyses and evaluation of received level modeling options. The received level models from the Naval Postgraduate School and from the Navy Acoustics Effects Model (NAEMO) were compared. Based on the analysis conducted, the team decided to move forward with the NAEMO for estimating received levels for the non-acoustic tags. During 2021, the team made significant progress refining analysis methods and continued to process data collected thus far. A comparison of modeled and recorded received levels from sonar exposures was presented at a scientific conference in March 2021 for feedback from the scientific community on the methodology.

During its final year, the project team focused on applying a hierarchical hidden Markov model

Fin whale.
*Gregory S. Schorr, permit 16111*

framework to analyze the response data from the CSEEs. Coordinating with Project 23 and its opportunistic data generated substantial data sets for analyzing cetacean behavior under different scenarios. The two types of data sets (coordinated exposure and opportunistic exposure) and data collected from both acoustic and non-acoustic monitoring tags also helped to refine analytical methods and to inform modeling results. Using only the SMRT tag data with acoustics from both the CSEE and OE data sets combined, the best fitting model found the probability of transition to the 'response' state depends on source-whale distance (not received level), with whales more likely to transition to a response as the distance decreases.

The resulting data also are a significant contribution to other Navy marine mammal behavior studies. The project team completed its final report and has presented information on the methods and modeling efforts at scientific meetings. Multiple publications are anticipated from the data collected within this project and Project 23.

The project demonstrated successful coordination with the Navy helicopter squadron that made possible the results that will allow the Navy to improve impact assessments. The results also are contributing to better estimates of the potential effects of sonar use on Cuvier's beaked whales and fin whales within the Southern California ranges.

### About the Principal Investigator

Stephanie Watwood manages the Marine Mammal Monitoring on Navy Ranges (M3R) Program in the Ranges, Engineering and Analysis Department at the Naval Undersea Warfare Center (NUWC). She has extensive experience in collecting and analyzing cetacean acoustic data, particularly related to cetacean behavior. Dr. Watwood holds a Ph.D. in biological oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography/Applied Ocean Science.

*Key collaborators: Karin Dolan and Joseph Fayton (NUWC), Greg Schorr, Erin Falcone, Brenda Rone, Russ Andrews, David Sweeney and Shannon Coates (Foundation for Marine Ecology & Telemetry Research (MarEcoTel)), Stacy DeRuiter (Calvin University).*

## DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling

**Principal Investigator: Len Thomas**
**Project Status: Completed, Project 31**

### NEED

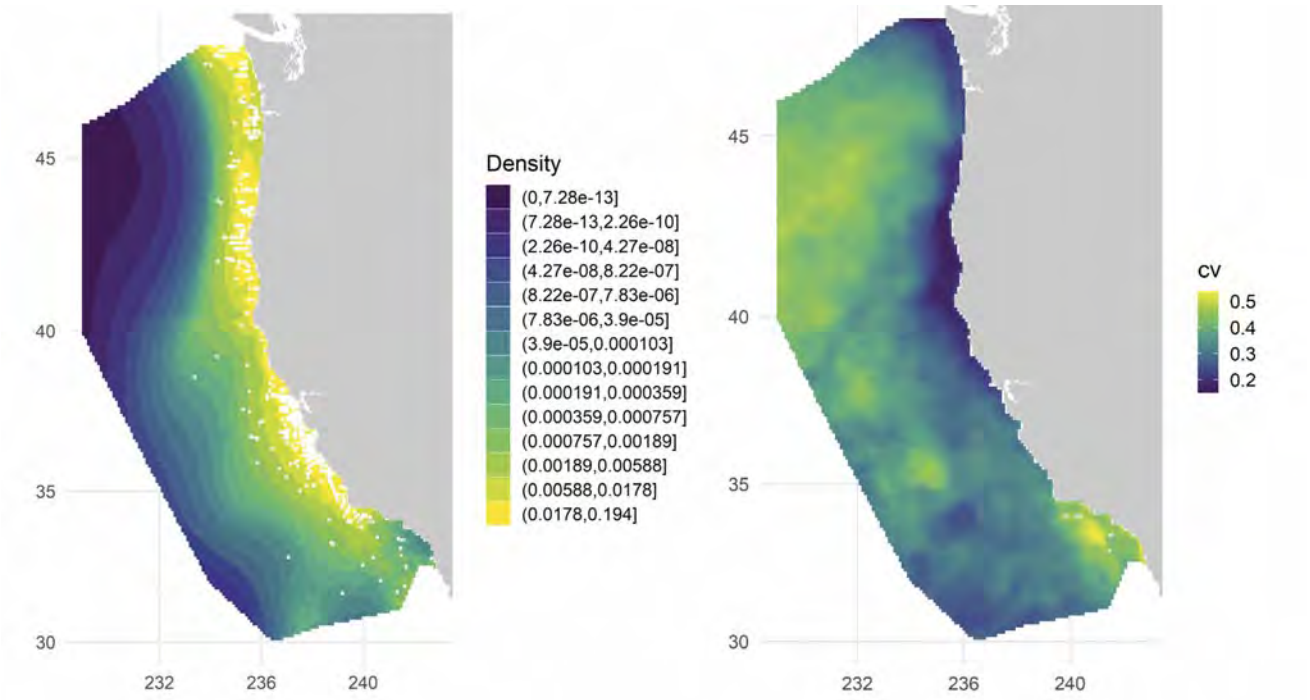
**N-0136-17: Coordination for the Advancement of Density Spatial Modeling Methods Using Visual and Acoustic Survey Data**

There is a need to identify and address priority issues in density surface modeling that are common to academia, NMFS Science Centers, Navy and other agencies. This need requires coordination of a working group, with involvement from stakeholders that can identify priority research issues and advance density surface modeling methods. The Navy needs advancements in density surface modeling methods to ensure that the best available science is used to determine take estimates.

### PROJECT

To estimate species density, statistical modeling can be applied to data collected from surveys of biological populations. One method, called a density surface model (sometimes called a spatial or habitat model), estimates animal population density as a function of spatially and, in some cases, temporally referenced oceanographic biotic and abiotic variables. These variables can include bathymetry, distance to ocean fronts, sea surface temperature and chlorophyll. Improvements to estimation procedures, including an increased understanding of the uncertainties associated with density estimates, are needed to improve the Navy's quantitative impact assessments.

In this project, a working group focused on developing and implementing innovative approaches to improve spatial modeling methods used to characterize seasonal abundance and distribution of




Predicted mean density (animals km$^{-2}$ ) and associated coefficients of variation (CV) from the 1991–2018 habitat-based density models for humpback whales. Panels show the multi-year average density based on predicted daily cetacean species densities covering the 1996–2018 survey periods (summer/fall). Predictions are shown for the study area (1,141,800 km$^2$). White dots in the average plots show actual sighting locations from the SWFSC 1996–2018 summer/fall ship surveys for the respective species.

*Jason Roberts, Duke University*

marine species. The DenMod project working group included the parties largely responsible for developing analytical methods and the collection and analysis of transect data used in Navy impact assessments: the University of St Andrews, Duke University and four regional NOAA Fisheries labs (Northeast, Southeast, Southwest and Alaska Fisheries Science Centers). To broaden the range of participants in the process, this group held three public workshops, two in advance of Society for Marine Mammalogy (SMM) conferences and one as an online webinar in 2022.

This project's outcomes are contributing to a substantial improvement in the reliability of the Navy's impact assessments in training and testing areas.

Initiated in 2017, the project formed the working group, which has met annually. Eight subgroups were formed to focus on key topics that participants identified (see Publications sidebar for citations):

1. **Uncertainty estimation**

   This subgroup focused on both correctly quantifying uncertainties related to individual model components and on how to combine these into final uncertainty estimates for maps and for abundance estimates (abundance is total number in a defined region—calculated as average density multiplied by area) (described in Miller et al. 2022). A tool for variance propagation has been developed in the industry-standard R programming language as part of the "dsm" package and the method is described in Bravington et al. (2021).

2. **Extrapolation**

   Density estimates in areas beyond the bounds of the survey data make assumptions on the correctness of the model used. The subgroup developed a guidance document along with a software toolkit that allows model assessment ("dsmextra", available online at: densitymodelling.github.io/dsmextra). Additional information was included in the peer-reviewed manuscript, "dsmextra: Extrapolation Assessment Tools for Density Surface Models" (Bouchet et al. 2020).

3. **Model unification**

   This subgroup looked at the similarities among various modeling techniques that have been used to obtain spatially explicit estimates of density, and completed a mathematical comparison of the different techniques, enabling a more informed choice of methods in the future. Results have been presented in three publications: Pederson et al. (2019), Miller et al. (2020) and Miller (2021).

4. **Workflow**

   Many data preparation and modeling workflows have evolved over time within the different organizations that provide density estimates to the Navy. The workflow subgroup led an effort to encapsulate this information. They have made a range of information and advice publicly available online at: osf.io/5eza8/wiki.

5. **Acoustic and visual data integration**

   This subgroup investigated methods for integrating density surfaces estimates derived from visual surveys and from separate, but spatially overlapping, acoustic surveys. The group initiated a case study using data from surveys of deep diving whales from NOAA's Northeast and Southeast Fisheries Science Centers, under the Atlantic Marine Assessment Program for Protected Species.

6. **Pinnipeds (seals and sea lions)**

   Pinnipeds raise unique issues when it comes to abundance estimation, as at-sea data are scarce,

but counts from haul-outs and movement data from tags are common. Operating under separate funding, this subgroup focused on working out how best to use and combine these disparate data. A paper led by the team at the Alaska Fisheries Science Center, describing the advancements that have been made, was published by ver Hoef et al. (2021).

This project has built new collaborations among agencies and universities, which will further advance the science of marine species density estimation.

7. **Tool development**

   This subgroup was formed to address requests from NOAA Fisheries Science Centers for software tools for modeling, validation and other analysis needs. Work on this has included improvements to the R package "dsm" and associated tools to support survey data modeling. One example, a tutorial on segmenting survey transects in R, is available online at: https://examples.distancesampling.org. Another is the ability to easily include data from multiple surveys each using a different survey platform (e.g., combining data from aerial and shipboard surveys), details of which are available in Miller et al. (2021).

8. **Unmanned aerial vehicles (UAV)**

   This subgroup investigated how to incorporate visual data from UAVs into density surface models. The subgroup worked with collaborators at Murdoch University and the Australian Antarctic Division to develop a case study on dugongs in Shark Bay, Western Australia. Mark-recapture techniques were used to obtain probabilities of detection for these surveys, which required adapting methods. This capability was added to the "dsm" R package.

Project participants have produced software tools that support the new approaches, and the group is developing concrete guidance on best practices in this type of modeling. Several products are available at the DenMod project website: denmod.wp.st-andrews.ac.uk.

This project's outcomes are contributing to a substantial improvement in the reliability of the Navy's impact assessments in training and testing areas. This has guided the Navy's future investment in refining the density estimates by focusing on high priority areas with a high degree of uncertainty. The Navy has benefited from this collaborative approach to advancing the density surface modeling methods that are applied in developing population estimates for the Navy impact assessments. In addition, this project has built new collaborations among agencies and universities, which will further advance the science of marine species density estimation.

### About the Principal Investigator

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 collaborators: David L. Miller and Catriona M. Harris (University of St Andrews), Pat Halpin, Jason Roberts, Ana Canadas, Tina Yack and Rob Schick (Duke University).*

## Publications by Year


Becker, E.A., Forney, K.A., Miller, D.L., Barlow, J., Rojas-Bracho, L., Urbán, R.J. and Moore, J.E. (2022). Dynamic habitat models reflect interannual movement of cetaceans within the California Current ecosystem. *Frontiers in Marine Science*, 9:829523. DOI 10.3389/fmars.2022.829523.

Miller, D.L., Becker, E.A., Forney, K.A., Roberts, J.J., Cañadas, A. and Schick, R.S. (2022). Estimating uncertainty in density surface models. *PeerJ*, 10:e13950. DOI 10.7717/peerj.13950.

Bravington, M.V., Miller, D.L. and Hedley, S.L. (2021). Variance propagation for density surface models. *Journal of Agricultural, Biological and Environmental Statistics*, 26(2):306-323. DOI 10.1007/s13253-021-00438-2.

Miller, D. L., Bayesian views of generalized additive modelling, arXiv e-prints (2021). DOI 10.48550/arXiv.1902.01330.

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Wakefield, E.D., Miller, D.L., Bond, S., Carvalho, P., Catry, P., Dilley, B., Fifield, D., Gjerdrum, C., González-Solís, J., Hogan, H., Laptikhovsky, V., Miller, J., Miller, P., Pinder, S., Pipa, T., Thompson, L., Thompson, P. and Matthiopoulos, J. (2021). The summer distribution, habitat associations and abundance of seabirds in the sub-polar frontal zone of the Northwest Atlantic. *Progress in Oceanography*, 198. DOI 10.1016/j.pocean.2021.102657.

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** Acknowledged contribution or expertise from the DenMod project.*

## Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar

**Principal Investigators: Elizabeth Henderson, Susan Jarvis, Tyler Helble, Peter Dugan**
**Project Status: Completed/Transitioned, Project 34**

### NEED

**N-0158-18: Evaluations and Standardization of Sonar Signal Processing Tools for Marine Mammal Research**

The Navy needs standard automated detectors for identifying U.S. Navy sonar sources within data sets used for passive acoustic monitoring (PAM) of marine mammals. The multiple automated sonar detectors currently in use by different researchers each produce varying results that are difficult to compare. To evaluate detection performance, the outputs from existing automated sonar signal detectors need to be statistically compared. Comparing the algorithms' performance using passive acoustic data sets with known occurrence of sonar signals (i.e., ground truthing) would provide a benchmark for assessing the probability of missed and false detections. In addition, there is a need to uniformly characterize sonar signal types into standardized groupings and terminology. This work will enable more comparable data analysis of behavioral responses observable within passive acoustic data. These results can then be used for criteria development and impact assessments.

### PROJECT

This project evaluated a set of standardized sonar detectors and classifiers, developed a new detector and completed a set of standardized nomenclature for Navy sonar signals. The project team included Navy investigators who assessed the efficacy and broad applicability of existing sonar detectors, which were provided with support by non-Navy researchers. The group worked to ensure that the greater research and signal detection communities would be able to have access to a standardized and generalizable sonar detector. Continued efforts to incorporate and refine the resulting application, SONAR, have been transitioned to a new LMR project (Project 62), Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses (page 96).

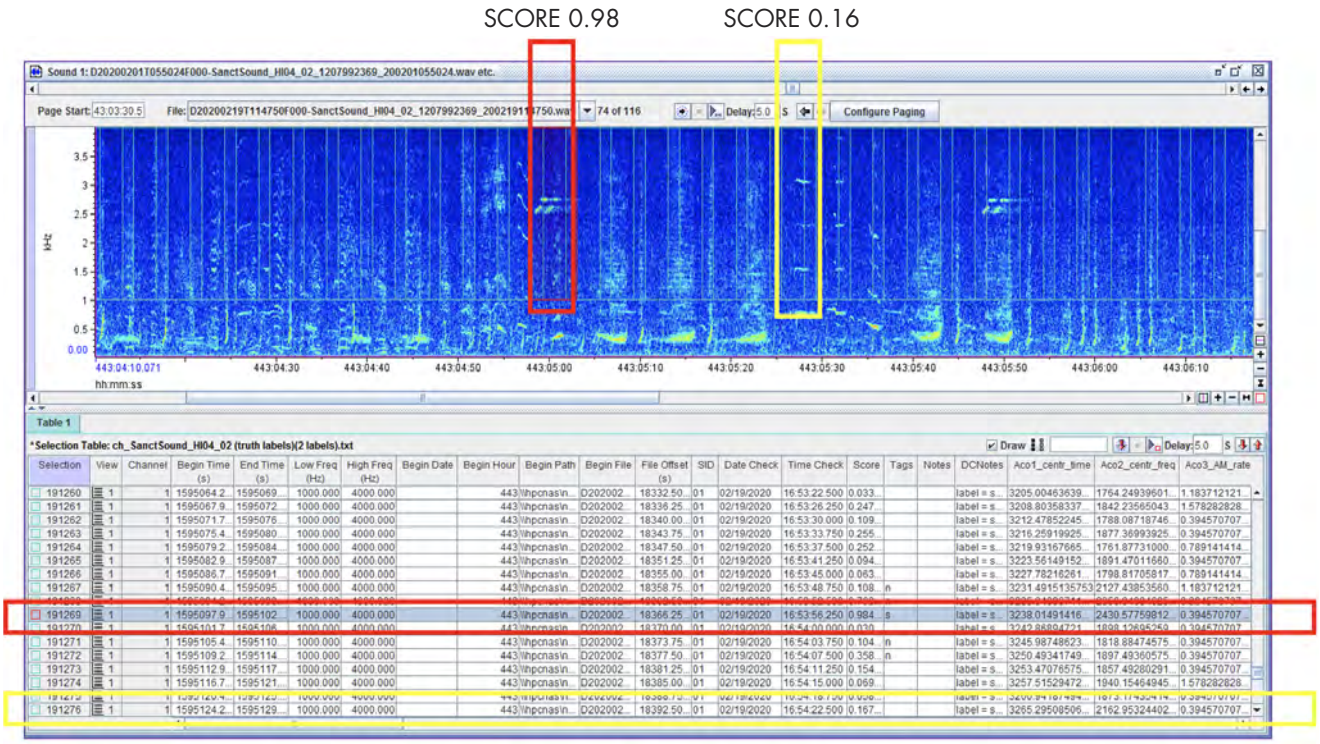
The project pursued six overall tasks, with project team member responsibilities carefully defined to protect classified information while working toward standardized non-classified methods:

Humpback whales.

1. Review literature for existing detectors/sonar signals descriptions.
2. Compile classified sonar data sets from Navy ranges.
3. Gather sonar detectors and non-classified sonar data from collaborators.
4. Run detectors on data sets.
5. Develop sonar detector/classifier (or suite of detectors if needed) based on results of comparison test.
6. Develop standardized nomenclature describing different signal types to be used by bioacoustics community.

Work during 2019 focused on the literature review, initiating work with collaborators, obtaining, testing and adjusting existing detectors and obtaining non-Navy sonar data. The literature review examined papers and reports with descriptions of sonar, including AN/SQS-53 hull-mounted, DICASS (directional command activated sonobuoy system) sonobuoys and AN/AQS-22 dipping sonar. The effort highlighted characteristics such as frequencies, source levels, sonar components, duty cycle, bandwidth and others. It also included identifying descriptors used in the Navy's Acoustics Effects Model (NAEMO). This helped to identify issues regarding the classification of sonar signals across platforms and organizations. The Navy sonar classification guidelines helped to select descriptive nomenclature in an unclassified way. The review also identified sonar descriptions that are already in the public domain (e.g., within environmental impact statements or published papers).

Work to compile classified sonar data sets from Navy ranges revealed tasks needed to select and prepare data sets for use. Tasks included digitiz-




Screen capture of the SONAR App in Raven-X, with an image of 140 seconds of SanctSound data that includes both humpback whale song and a few instances of sonar. Two sounds are boxed in red and yellow in the spectrogram, as well as in the detection results at the bottom of the screen. The red box highlights a real MFAS waveform, which was scored very highly at 0.98 out of 1.00. The yellow box highlights a humpback vocalization that was scored poorly at 0.16 out of 1.00. These results demonstrate how well the SONAR shallow neural net does at picking out sonar signals, even when other sounds are present.

ing data, defining recording length, and identifying data issues such as clipping, harmonics and noise. Data also had to be cleared by an additional Navy organization to ensure data could be used for classification.

The project evaluated four available detection programs: Cornell's Sonar detector within Raven-X, Bio-Waves' SonarFinder, a generalized power-law (GPL) detection algorithm, and the Silbido detector from San Diego State University and the University of California San Diego. Initial results helped to identify potential pitfalls in detector comparisons, data preparation steps that might be required prior to analyses and core characteristics that might be appropriate for a standardized detector.

Following more in-depth analyses of detector capability comparisons and applying detectors to more data sets, the team focused on using Raven-X as the analysis platform and worked to incorporate the existing detectors mentioned above. Using the Raven-X platform, the team was able to run all the detectors in parallel on the same data set, over a variety of detector settings. This capability was instrumental for properly comparing the detectors in a timely manner and generating comparable statistics for analysis. Raven-X was also used to train a machine learning "shallow net" for the GPL and Cornell detectors.

The team used both unclassified data and real Navy training data from the Pacific Missile Range Facility (PMRF). The testing work encompassed: 1) comparing results across detectors against manually validated detections; 2) generating multiple performance metrics (e.g., precision/recall curves, ROC curves, DET curves) and 3) using Detection, Classification, Localization (DCL) Committee standards to score and assess each detector's relative performance. The tests revealed that the existing detectors had been optimized to perform best on their original data sets and were less reliable for use on other data sets.

The team then redirected its efforts from adapting an existing detector to developing a new detector. Continuing work in Raven-X, team members employed a subset of data from Scripps Institution of Oceanography, Cornell University and PMRF to train, test and evaluate the new detector based on the shallow neural net developed in Raven-X. The data included 770 sonar and 19,300 non-sonar examples.

> Products from this effort include an automated detector and a technical report that outlines a set of standardized unclassified sonar nomenclature.

To broaden testing of the new detector, the team collaborated with the Sanctuary Soundscape Monitoring Project (SanctSound). SanctSound is a four-year project managed by NOAA and the U.S. Navy to better understand underwater sound within national marine sanctuaries. Passive acoustic monitoring devices were placed at 30 recording locations in seven sanctuaries and one marine national monument within the sanctuary system. The project team used 17 data sets from eight of the SanctSound recording locations, including five in the Hawaiian Islands Humpback Whale National Marine Sanctuary and three in the Papahānaumokuākea Marine National Monument. Many of these data sets contained sonar and humpback whale calls. SanctSound data analysts provided manual detection logs from two locations to validate the sonar detector output in the presence of humpback singing. Initial runs indicated that the sonar detector works well, with fewer than three false detections per hour. For comparison, 20 false

detections per hour is the cutoff for determining if a detector is useful.

During 2022 the team analyzed the remaining Hawaiian Island SanctSound data sets for the presence of sonar. Work on the sonar detector included testing it on additional Navy range data and transitioning the tools to the Naval Information Warfare Systems Center and providing training on the application.

For the sonar nomenclature effort, the team organized a standardized and unclassified nomenclature for describing sonar signal detections in passive acoustic data sets. They began by identifying sonar descriptors used in NAEMO. They shared the initial set with U.S. Fleet Forces sonar operators both to ensure accuracy and to avoid classified information. Drawing on feedback, the team has developed a technical report of recommended nomenclature.

The project team presented project results at the 2022 Detection, Classification, Localization and Density Estimation meeting, where they also shared the nomenclature report with interested researchers.

Products from this effort include an automated detector and a technical report that outlines a set of standardized unclassified sonar nomenclature. The automated detector can detect the presence of sonar in marine mammal PAM data sets and has been demonstrated to have a consistently high rate of performance. Included with the detector are recommendations on tuning the characteristics of the detector for optimal use. The technical report identifying standardized unclassified sonar nomenclature is available to researchers upon request. Future research funded by Navy programs will encourage the use of these tools and methods to detect sonar on recorded acoustic data. This will promote comparable results from independent research on the effects of Navy training and testing activities, including Navy sonar, on marine life.

**About the Principal Investigators**

Elizabeth Henderson is a bioacoustics scientist at the Naval Information Warfare Systems Center. Dr. Henderson earned her Ph.D. in biological oceanography and bioacoustics at the University of California San Diego. She focuses on marine mammal acoustic behavior and noise impact analyses for environmental compliance.

Susan Jarvis is an electronics engineer at the Naval Undersea Warfare Center, Newport and an assistant teaching professor at Worcester Polytechnic Institute, Worcester, Massachusetts. Dr. Jarvis earned her Ph.D. in computer engineering at the University of Massachusetts Dartmouth. Her work focuses on real-time acoustic signal processing for real-time detection, classification and localization of marine mammals.

Tyler Helble is a bioacoustics scientist and electrical engineer at the Naval Information Warfare Systems Center, Pacific. Dr. Helble earned his Ph.D. in applied ocean sciences 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.

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.

# 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 11 ongoing projects and one new start project.

The ongoing projects are

1. Project 26—The Effects of Underwater Explosions on Fish
2. Project 32—Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals
3. Project 37—Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales (SOST)
4. Project 38—Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds (SOST)
5. Project 40—Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles
6. Project 45—Frequency-dependent Underwater TTS in California Sea Lions
7. Project 47—Standardizing Auditory Evoked Potential Hearing Thresholds with Behavioral Hearing Thresholds
8. Project 50—Loudness Perception in Killer Whales (*Orcinus orca*); Effects of Temporal and Frequency Summation
9. Project 51—Dependence of TTS on Exposure Duration During Simulated Continuously Active Sonar: Examining the Equal-energy Hypothesis for Long-duration Exposures
10. Projects 52, 53 and 54—Studying Marine Mammal Behavioral Response to SURTASS LFA Sonar
11. Project 55—Dolphin Conditioned Hearing Attenuation.

The new start project is

1. Project 61—Auditory Masking in Odobenid and Otariid Carnivores.

## Ongoing Projects

### The Effects of Underwater Explosions on Fish

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

#### NEED

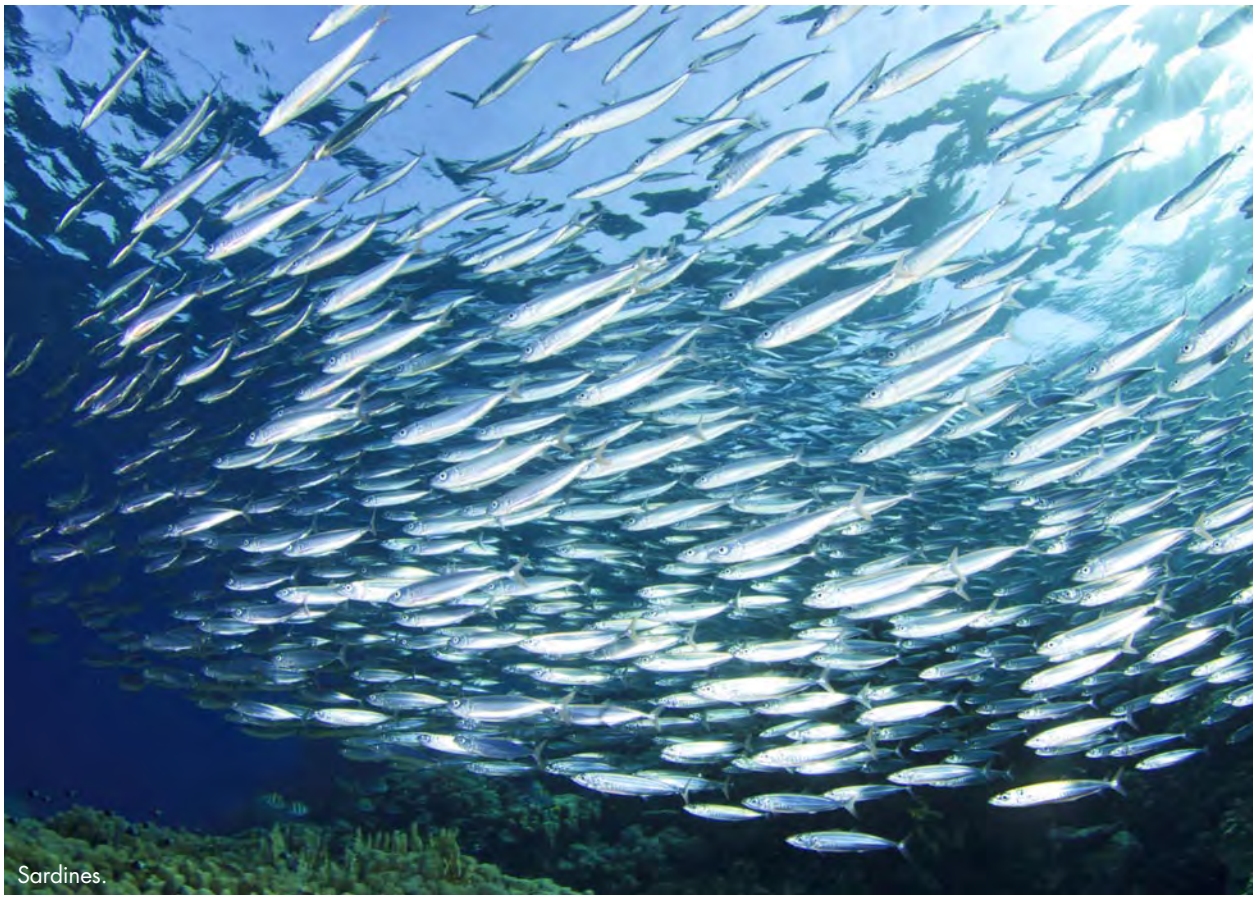
**N-0103-16: Marine Species Hearing Research Related to the Acoustic Effects Criteria**

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.

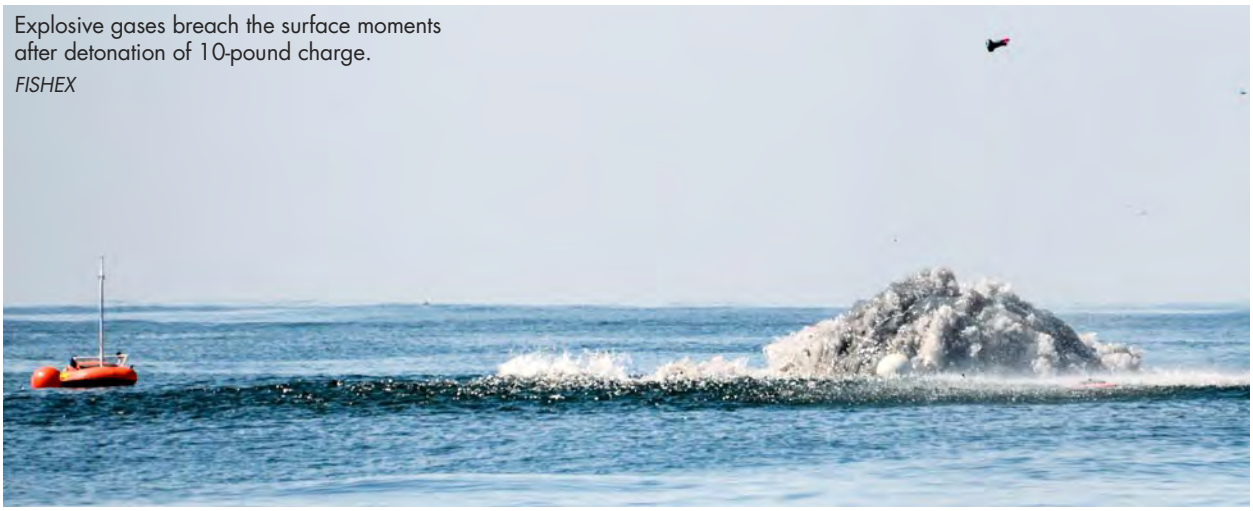
#### PROJECT

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 have 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 is studying explosive effects on fish species with differing characteristics (e.g., swim bladder morphology) and size, at varied



Sardines.



Explosive gases breach the surface moments after detonation of 10-pound charge.
*FISHEX*

water depths and distances from the source. Tissues from exposed fish (as well as from an extensive set of control samples) were examined using well-established necropsy techniques. Careful attention was focused on ensuring a statistically valid experimental design. This approach will provide a broader and more comprehensive understanding of potential effects and dose-response relationships.

> Careful attention was focused on ensuring a statistically valid experimental design.

The Phase I trials completed in 2018 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 at the 2019 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. Pacific mackerel (*Scomber japonicas*) were used in these trials, representing 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 the LMR 2020 Annual Report for citation). 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.

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 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.

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

> Project results will support refinement of the Navy's criteria for impacts to fish from explosive sources.

Data analyses during 2022 focused primarily on data from the 2021 Pacific mackerel trials (Phase III) and were nearing completion by the end of the year. Work in 2023 will focus on completing two additional manuscripts. One will report on results from the 2021 Pacific mackerel trials (Phase III) and the other will provide an overall project review and proposed thresholds. Project results will support refinement of the Navy's criteria for impact to fish from explosive sources.

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 2022

Jenkins, A.K., Dahl, P.H., Kotecki, S., Bowman, V., Casper, B., Boerger, C. and Popper, A.N. (2022). Physical effects of sound exposure from underwater explosions on Pacific mackerel (*Scomber japonicus*): Effects on non-auditory tissues. *The Journal of the Acoustical Society of America*, 151(6):3947. DOI 10.1121/10.0011587.

Smith, M.E., Accomando, A.W., Bowman, V., Casper, B.M., Dahl, P.H., Jenkins, A.K., Kotecki, S. and Popper, A.N. (2022). Physical effects of sound exposure from underwater explosions on Pacific mackerel (*Scomber japonicus*): Effects on the inner ear. *The Journal of the Acoustical Society of America*, 152(2):733. DOI 10.1121/10.0012991.

## 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

Navy training and testing activities occur in waters surrounding the Hawaiian Islands, including areas overlapping habitat for the ESA-listed Hawaiian monk seal (*Neomonachus schauinslandi*). However, there are few bio-acoustic data available for the monk seal, including information about hearing abilities and the production of underwater sounds. The lack of substantive information available for the species makes it difficult to make science-based decisions relative to the possible effects of naval and other anthropogenic activities on these marine mammals.

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

Monk seal KP2.
*Colleen Reichmuth, permit 24054*

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

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

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 male seals 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

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

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

The project also created an educational video for Waikiki Aquarium describing KP2's research in Santa Cruz. The video can be found at: www.waikikiaquarium.org/experience/exhibits/hawaiian-monk-seal-habitat/.

In 2023, the team will work to complete all hearing measurements and evaluate the data against results collected from KE18. 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 2023.

The results of this effort will 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 auditory research with marine mammals with a focus on behavioral psychoacoustic methods. 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 bio-acoustician 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 collaborators: 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 119 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 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 suit-

Juvenile minke whale.
*Rune Roland*


Study site net-enclosed fish farm.

able 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.

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

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 broad-band 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.

> Techniques developed during the minke whale hearing tests also will facilitate future audiometric measurements on other mysticete species.

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 will return to Norway in 2023 for a third field season.

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, determining low-frequency thresholds will provide information needed to establish 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 119, 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 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

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

(based on assumptions about their hearing in noise conditions). 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, it is expected that the focal group will change behavior by avoiding the source vessel. This is repeated multiple times for each frequency, using different groups of whales. Experiments in which the vessel will be present, but no tones are transmitted, are 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 will be 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 close to the projected path of the group.
3. During phase—Operate the sound source as the group approaches until the signal is detected and the whale 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 11 previous field seasons on humpback whale behavior and acoustics that provide a wealth of background data on whale movements, normal behaviors and abundance. 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

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*

staffing for the land-based observers by approximately one-third. The 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.

The resulting information on humpback whale hearing will help regulators, industry and the U.S. Navy to model the potential effects of noise-producing activities on humpback whales.

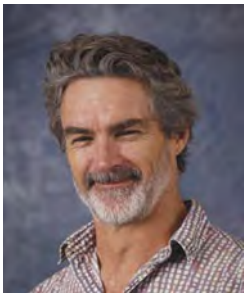
During 2022, the team completed data analyses from the 2021 field work and used insights from that season to refine the experimental plan for the 2022 field efforts. With COVID restrictions removed, the team was able to employ a full complement of 12 volunteers, which significantly improved data collection. A total of 27 sound, three control (no sound transmission) and six baseline trials (i.e., no source vessel in area) were successfully completed. Frequencies tested in 2022 included 250 Hz (sweeping up to 315 Hz), 1 kHz (sweeping up to 1.25 kHz), 4 kHz (to 5 kHz) and 16 kHz (to 20 kHz). During five of the trials, Acousounde (sound recording) tags were deployed, with four successfully recording data (one failed to record). Data analyses were largely completed by the close of 2022 and the results will inform the 2023 field plan. Preliminary results show that the study design is effective at eliciting a response that is indicative to the sound being heard.

The team will conduct one more round of field trials in 2023, and 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.

## 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.

Eastern painted turtle.
*Andria Salas*


Green sea turtle.

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 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

Loggerhead sea turtle.
*NOAA*

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.

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

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.

Work in 2023 will include quantifying potential auditory impacts from noise exposures, finishing testing TTS for higher 1/6 octave (narrow) band noise, addressing additional SPL/exposure duration combinations to build a larger SEL matrix for each fatiguing noise and exploring anatomy to quantify potential auditory impacts from noise exposures.

Because no TTS data currently exist for turtles, the audiograms and TTS data produced by this research will inform analyses of the effects of sound-producing activities on 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.

## 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

California sea lion Loes (F01) in D-tag harness with assistant Laura.
*Ron Kastelein*

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.

California sea lion Billy (M02). *Rani van de Vlist*

Two California sea lions, an adult female and a young male, with excellent hearing are being tested within a pool complex designed for acoustic studies. The animals are exposed to the fatiguing sounds and their hearing is tested pre- and post-exposure. The fatiguing sounds are 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 are being 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 is collecting 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 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 will be 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. Following the initial recordings, the sea lion resisted the harness, delaying addition data collection. A new harness was developed, and new training initiated. Once the animal accepts the harness again, each fatiguing sound will be 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 is 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 Publications sidebar for citations) and three additional manuscripts were in preparation.

Work planned for 2023 will include completing data collection using the DTAGs, completing audiograms for California sea lions and completing the three in-preparation manuscripts.

This project will produce 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 will inform the validity of the equal energy hypothesis and provide new insights regarding the effect of duty cycle on TTS. The project will also provide 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 will be 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 will be directly applicable to all Navy environmental documents analyzing acoustic effects of tonal sounds (e.g., sonars) and broadband sounds (e.g., explosions).

### About the Principal Investigator

Since 2002, Ron Kastelein, Ph.D. (University of Wageningen, The 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., Van Acoleyen, L., Huijser, L.A.E. and Terhune, J.M. (2022). Temporary hearing threshold shift in California sea lions (*Zalophus californianus*) due to one-sixth-octave noise bands centered at 0.6 and 1 kHz. *Aquatic Mammals*, 48(3), 248-265. DOI 10.1578/AM.48.3.2022.248.

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

## 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

Bottlenose dolphin.
*Wayne Hoggard, NOAA*

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.

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 sub-

Collecting AEP threshold data.
*Dorian Houser*

merged 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.

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

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 all 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.

Work planned for 2023 includes working with the National Marine Fisheries Service (NMFS) on how the results might apply within NMFS criteria and preparing manuscripts for publication. The AEP audiograms identified as behaviorally equivalent will be published as a U.S. Navy Technical Report and provided to Navy personnel.

These 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 the 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 subjective loudness of short-duration signals compared to long-duration signals.

In addition, the relative loudness of multicomponent signals will be 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

Killer whales.

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 Sea World in a quiet and isolated pool that supports an exceptional amount of experimental control over the testing environment and acoustic stimuli.

The effort is organized around the following three 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. **Subjective loudness comparison for different duration signals**

   This experiment will directly measure perceived loudness. Two tones will be presented, and the whale will indicate which sound (the first or second) is perceived louder by pressing a corresponding paddle (i.e., paddle one if the first sound is louder or paddle two if the second sound is louder). Within each session, the frequency of the two tones will be the same.

3. **Loudness of multicomponent signals**

   This experiment will test how perceived loudness of broadband sounds compares to pure tones and will provide data indicating how the harmonic components in Navy sonar signals may be perceived as louder than 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 experiment 2 (subjective loudness comparison for different duration signals). This phase is using 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

Killer whale.

welded by SeaWorld) and animal training for the new experimental protocols. Three whales were in training for experiment 2.

One manuscript was published in 2022 (see Publications sidebar for citation) and two additional manuscripts are planned during the remainder of the project.

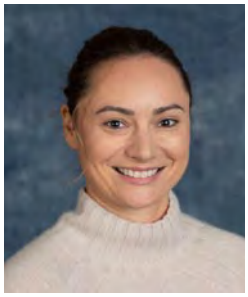
Work in 2023 will include training and data collection for experiments 2 and 3, data analyses and manuscript preparation.

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.

This study will provide the necessary data to modify current auditory weighting functions to include both pulsed tones and broadband sounds.

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. Defining the relationship between perceived loudness and 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 is a research scientist with the National Marine Mammal Foundation and serves on the Animal Bioacoustics Technical Committee for the Acoustical Society of America. She pursues both basic and applied research that focuses on auditory processing and perception in echolocating animals. Dr. Accomando 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. and Sills, J.M. (2022). Mechanisms of auditory masking in marine mammals. *Animal Cognition*, 25:1029-1047. DOI 10.1007/s10071-022-01671-z.

## Dependence of TTS on Exposure Duration During Simulated Continuously 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 Continuously Active Sonar**

Results from previous behavioral response studies have indicated that both the type and the duration of Navy sonar signals may play a role in observed responses in marine mammals. As sonar technologies change, the Navy needs new information on the effects of new types of sonar on marine mammal hearing and behavior. Continuously 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 continuously 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 continuously 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 continuously 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

Bottlenose dolphin.

exposure levels (SEL) result in equal TTS. Therefore, the short, high sound pressure levels (SPLs) of pulsed sonar are considered equivalent—in terms of TTS—to lower SPL continuous exposures that have the same cumulative SEL. However, while source and received SPLs of CAS may be lower than those of pulsed sonars, accumulated SEL may be high due to the high duty cycles of CAS, as fewer quiet periods will be present during which SEL does not accumulate.

The project goals 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 noise exposure.

> The data from this project will test how conservative the equal energy assumption may be for moderate-level CW and LFM exposures.

The fatiguing stimuli used to induce TTS are both CW tones and FM tones with bandwidths characteristic of CAS. Energy in the FM signals are being modulated over one octave; thus, it is expected that TTS effects will be smaller than those


The hearing tests are conducted from an experimental shack located near the dolphin's floating netted enclosures. Researchers communicate with trainers via headset and monitor the dolphin's behavior using a listening hydrophone and video camera.

observed for CW tones, which have noise energy distributed over a larger area in the frequency map in the inner ear.

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.

During 2022 the project conducted animal training for hearing tests and initiated baseline hearing and 28-kHz TTS measurements with two dolphins (a combined total of 69 noise exposure sessions). When testing indicated that one dolphin without a full range of hearing had markedly elevated TTS thresholds, a third animal was trained and tested (a total of 33 noise exposure sessions). Testing could not be completed as planned within 2022 because a Navy dredging project in the testing area required temporarily relocating the animals. While TTS stationing training could be conducted at the new location, additional noise exposures were deferred. Also, during 2022, a presentation abstract was published (see Publication sidebar for citation).

Work in 2023 will include completing the 28 kHz TTS measurements and conducting the 3 kHz TTS measurements. The project team will prepare manuscripts for peer-reviewed publication.

The data from this project will test how conservative the equal energy assumption may be for moderate-level CW and FM exposures at durations of up to an hour. A potential goal is to determine a duration-based correction factor for TTS onset criteria to include in Navy criteria. Additionally, comparing CW and FM TTS data will inform if the FM is less likely to induce TTS. These results 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-investigators are Dr. Alyssa Accomando (NMMF) and Dr. James J. Finneran (Naval Information Warfare Center, Pacific).

### Publication

Mulsow, J., Schlundt, C. E., Accomando, A. W., and Finneran, J. J. (2022). Temporary threshold shift from continuous 20–40 kHz hyperbolic upsweeps in bottlenose dolphins (*Tursiops truncatus*), *The Journal of the Acoustical Society of America*, 152, 108.

## Studying Marine Mammal Behavioral Response to SURTASS LFA Sonar

**Principal Investigators: Multiple (see text)**
**Project Status: Ongoing, 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.

> The goal of this effort is to update previous studies done with LFA sources during the 1990s.

### PROJECT

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

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.

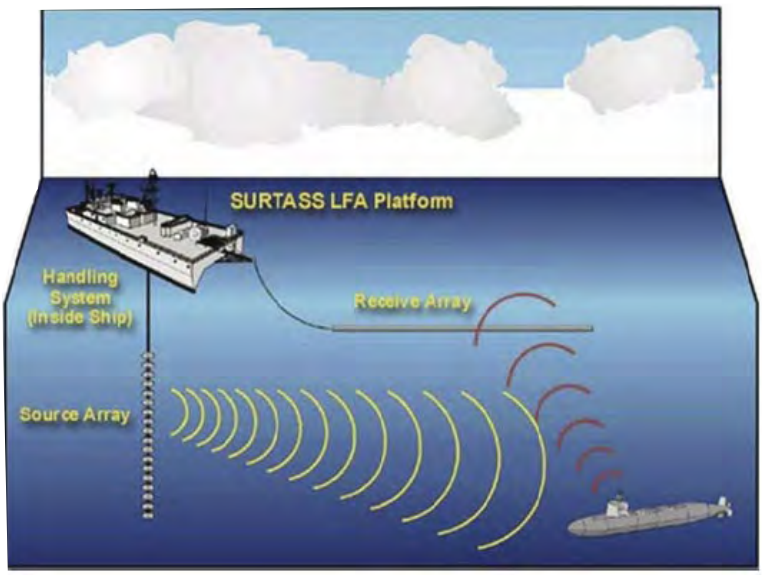


Diagram showing operation of a Navy SURTASS LFA platform at sea.

This is following a two-phase approach. Phase I, initiated in 2021, is a feasibility study to investigate the best approach to designing a scientific study to assess behavioral response to LFA sonar. This will involve 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 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.).
- 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).

Phase I, started in November 2021, was nearing completion by the end of 2022. Each project presented its current 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, are expected early in 2023.

Phase II 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 data will be provided to the Navy and will support the at-sea environmental compliance community in environmental criteria development.

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: Ongoing, 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

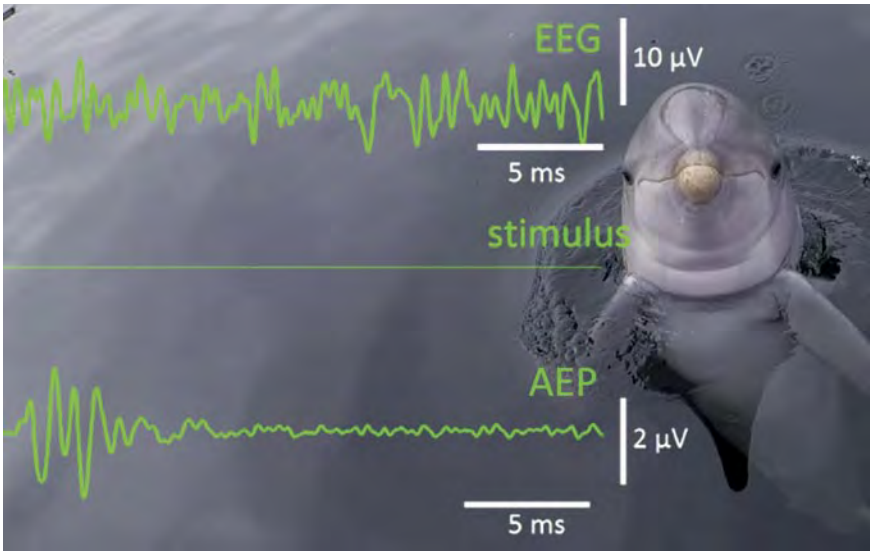
This project is focused on three primary objectives:

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 is co-funded by the LMR program and the NIWC Pacific Naval Innovative Science and Engineering (NISE) program. The project team is assessing 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 is working 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 are 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 are 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 sound). Across experimental sessions, features of the AEP stimulus, the warning sound and the intense sound are




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

manipulated to reveal temporal and spectral characteristics of the conditioned hearing attenuation phenomenon.

A research assistant monitors dolphin AEPs (center screen) and the dolphin's position (right screen) during a conditioned hearing change session

Measurements of AEPs in the presence of on- and off-frequency masking noise will be made to identify an AEP correlate for proper outer hair cell function. If successful, these AEP measurements will be conducted during periods of conditioned hearing attenuation to determine if the attenuation is mediated by changes to outer hair cells/cochlear amplifier gain.

The project began in late 2021 with work refining testing procedures, conducting baseline testing and determining 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 a manuscript discussing the results was submitted and accepted for publication. It is scheduled for publication in early 2023.

> The results will improve understanding of the potential impacts of conditioned hearing attenuation on marine mammal hearing and on current acoustic criteria.

In 2023, a warning sound will be paired with the intense sound to test if the dolphins learn to associate the warning sound with the intense sound and attenuate their hearing. Once the conditioned hearing attenuation is established, testing will focus on how long the dolphins can maintain the conditioned hearing attenuation. This will be accomplished by randomizing the time between the warning and intense sounds, then gradually increasing the upper limit of the random time interval.

Work in 2023 will also include an experiment to evaluate the role of outer hair cells in conditioned attenuation. Two additional manuscripts presenting results are planned by the close of 2023.

The results will improve understanding of the potential impacts of conditioned hearing attenuation on marine mammal hearing and on 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 Naval Information Warfare Center (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.

# New Start Project

## Auditory Masking in Odobenid and Otariid Carnivores

**Principal Investigators:**
**Colleen Reichmuth, Jillian Sills**
**Project Status: New Start, 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 will provide 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 supplements 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 enables the project team to expand the study scope to include a California sea lion (*Zalophus californianus*) and collect additional comparative data. The study will provide new information relevant to noise exposure criteria for the marine mammal functional hearing group designated as "Other Marine Carnivores." This is a grouping of amphibious marine mammals that are not phocids (true seals), which includes sea lions, fur seals, walruses and sea otters. They are among the least studied marine mammals with respect to hearing and the effects of noise, yet they occupy areas of the northern Pacific and Arctic waters essential to U.S. Navy operations.


California sea lion.

The project is working with trained marine mammals at SeaWorld San Diego and the University of California Santa Cruz. The team collects hearing data by conducting behavioral audiometric testing in outdoor conditions. Walrus and sea lion subjects learn to position calmly within a calibrated sound field and then report the presence of a tone by touching a target or withhold responding in the absence of a tone. Tone frequency and level are varied over hundreds of trials to measure hearing thresholds. Hearing thresholds are measured in ambient conditions for 1-second tonal signals from 0.08 to 16 kHz for walruses and from 0.08 to 32 kHz for sea lions.

Pacific walrus Mitik, a subject in cooperative hearing assessments.
*Colleen Reichmuth, permit 23554*

In addition to ambient hearing thresholds, the team will also measure masked hearing thresholds for the same tonal signals in the presence of controlled background noise (octave-band noise centered on the test frequency). Auditory critical ratios—which will be determined for each frequency—are a key parameter of auditory masking and can be used to predict the effects of noise on hearing for these species. The application of these data will be validated using the hearing measurements obtained in natural noise. Importantly, the auditory critical ratios to be measured in this study can be used to predict masking arising from both underwater and airborne noise.

Several tasks were initiated under separate funding, which has helped to move the overall project ahead. During 2022, the team completed data collection with three animals (a California sea lion and two walruses). Measurements included ambient and masked low-frequency hearing thresholds with both species, which extends the frequency range evaluated in this study from 80 Hz to at least 16 kHz. The sea lion data will serve as validation for the outdoor testing method because this individual's hearing was previously measured at the same frequencies in a controlled acoustic environment.

> 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.

Work in 2023 will include analyzing data and preparing and submitting a manuscript for publication.

The auditory data resulting from the proposed study will improve environmental impact assessments of potential acoustic effects resulting from Navy training and testing activities in Pacific Northwest waters, including Oregon, Washington and Alaska, and in Arctic regions.

> This project will contribute to data sets used to establish acoustic exposure criteria for free-ranging animals in both air and water.

These areas include overlapping habitat for both otariid and odobenid carnivores. 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. It will contribute to data sets used to establish acoustic exposure criteria for free-ranging animals in both air and water.

Graduate student Ryan Jones with trained sea lion Ronan.
*Colleen Reichmuth, permit 23554*

### 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 auditory research with marine mammals with a focus on behavioral psychoacoustic methods. 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).*

## INVESTMENT AREA 2
## DATA PROCESSING AND ANALYSIS TOOLS

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

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

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

The ongoing projects are

1. Project 42—ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation
2. Project 43—MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance
3. Project 44—Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales
4. Project 49—Combining Global OBS and CTBTO Recordings to Estimate Abundance and Density of Fin and Blue Whales.

The new start projects are

1. Project 58—Bryde's Whale Cue Rate and Kinematics
2. Project 60—Historic ARP and HARP Passive Acoustic Recording Archiving with NCEI
3. Project 62—Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses
4. Project 65—Using Passive Acoustic Tracks from a Navy Array to Study Large Whale Behavior in the North Atlantic.


MC3 Moises Sandoval

# 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 as well as contacting 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 recommen-

Narwhals.
*Kristin Laidre, NOAA*

dations for PAM data sources. (See the 2021 LMR Annual Report for 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.

Marine mammal density estimates are a critical element of the Navy's acoustic effects modeling, which supports environmental compliance.

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 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 data sets, was developed and circulated for comment. A revised version was in review at the end of 2022. Nearly 850 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.

Analyses of deep diver cue rate variability, using sperm whale data from three years of line-transect surveys, were initiated in 2021. The work included analyzing 42 hours of data and annotating 119,000 clicks in the data by the end of 2021.

Other work started or ongoing in 2021 included estimating cue rates for baleen whales by analyzing acoustic and auxiliar sensor data from right whales, blue whales and fin whales. In 2022, the team continued work on evaluating data from the different types of tags (i.e., time-depth recorders vs acoustic tags), refining methods and determining how proxy data could be used to estimate cue rates. A paper will be submitted in early 2023 describing the conditions under which one might be able to identify the tagged animal as the calling animal for baleen whales.

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

With the bibliographic review and tag processing largely completed during 2022, project work in 2022 next focused on assessing factors influencing cue rates, refining methods to identify cue rates from proxy data, evaluating deep diver cue rate variability and defining detector/classifier implications for cue rates. The analyses of sperm whale tag data during 2022 focused on sound production rates and how to estimate cue rates from tags without acoustic recorders. Detailed analyses of narwhal tags data were also conducted. Multiple manuscripts were in preparation at the end of 2022.

Evaluations of how signal detector/classifiers might affect cue rate estimations, started in late 2021, were continued in 2022. 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 what a cue rate is (e.g., single clicks, multiple clicks in close succession). Results of this and other work are targeted for publication in 2023.

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. 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 with 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 (Texas A&M University, Galveston, USA), 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).*

## MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance

**Principal Investigator: Cormac Booth**
**Project Status: Ongoing, Project 43**

### NEED

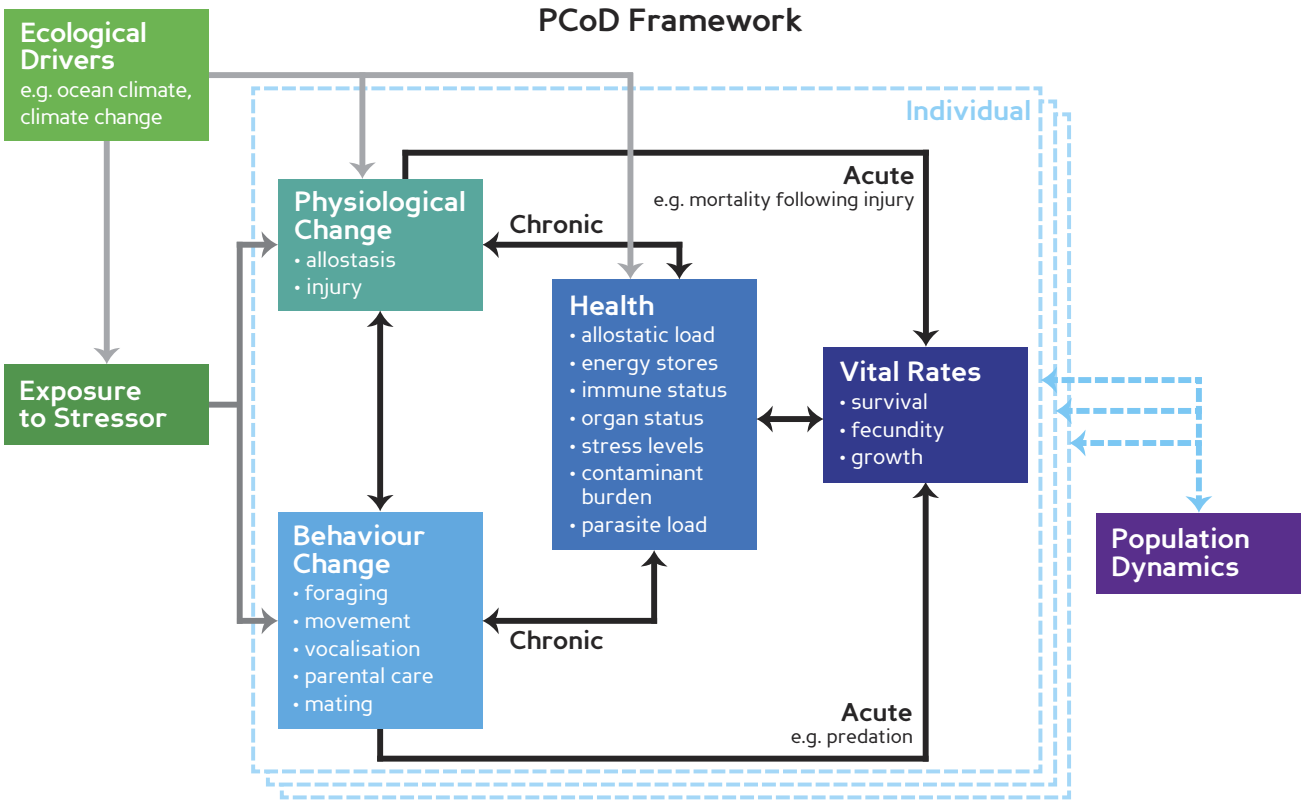
**N-0207-19: Identification of Monitoring Priorities for Studying the Population Consequences of Disturbance on Marine Mammals**

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 is 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 aims to estimate the power of current monitoring efforts to detect changes in population size and improve methods for detecting early warning signs of change. This project will assess how well current Navy MSM

Cuvier's beaked whale.




program efforts can support PCoD analyses and, filtered by feasibility of methods, recommend what could be improved.

There are 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 will include assessing the monitoring that has been conducted over the past 20 years of the MSM effort. For each monitoring study, the team will document 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 will be 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 will be 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 will help 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 detection of an effect, such as changes in population size and demographics. Conducting power analyses on information from the monitoring program will indicate whether MSM efforts to date can support PCoD analyses and will help to identify what efforts would be required for different species/method/metric combinations. A series of power analyses for a

minimum of two priority case study species (likely one deep diving odontocete and one large whale species), as determined by the most suitable species from the MSM review, are expected.

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

The results of these efforts will be synthesized in a report that also provides recommendations for how the MSM program could inform PCoD analyses.

In 2020, the project team began by holding 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.

The priority species by region defined for the project are

- Atlantic Fleet Testing and Training (AFTT)
  1. Cuvier's beaked whale
  2. Short-finned pilot whale
  3. Sperm whale
  4. Humpback whale
  5. Fin whale
  6. North Atlantic right whale
- Pacific (Hawaii & SOCAL-HSTT)
  1. Cuvier's beaked whale
  2. Blainville's beaked whale
  3. Short-finned pilot whale
  4. False killer whale
  5. Humpback whale
  6. Minke whale (lower priority)
  7. Bryde's whale (lower priority).

Databases of Atlantic and Pacific monitoring studies were largely completed in 2021. Each data spreadsheet contains a tab for each data type and includes data columns specific to data collection method. For example, acoustic data collection details include type of PAM device, number of detections and recording hours. For tasks 2 and 3, the project team also began selecting metrics, using bioenergetic models for relevant species and developing an analytical framework for determining how best to combine multiple data streams into improved power analyses. After completing the draft 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 Southern California (SOCAL), Hawaii and Hatteras regions. The team then decided to focus efforts on this species in the SOCAL region.

> Project results will also include a set of practical recommendations of how PCoD elements could be incorporated into existing MSM efforts.

During 2022, the project team completed reviewing monitoring studies and nearly finished adding the information to the review spreadsheets. Much of the year's work focused on testing and refining selected metrics, testing and

Short-finned pilot whales.
*Adam U, NOAA*

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 during 2022, including developing an Integrated Population Model for SOCAL Cuvier's beaked whales. This approach is expected to show how different survey methods (e.g., photo-ID, line transect surveys, etc.) can change the statistical power to detect population changes. The Integrated Population Model will also look at how combining the different survey methods can further improve power to detect changes in population size. This is a generalized model framework that could be applied to different species and regions. The model is expected to be ready in summer 2023.

Overall project results will also include a set of practical recommendations of how PCoD elements could be incorporated into existing MSM efforts. This offers the opportunity for Navy monitoring of consequences to focus on those species and populations best studied for identifying PCoD. This will help to enhance the information collected and the analyses produced by marine species monitoring, which will increase monitoring benefits.

### About the Principal Investigator

Cormac Booth is Principal Scientist 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, Ursula Verfuss and Rachael Sinclair (SMRU Consulting, University of St Andrews, UK), Len Thomas and Eiren Jacobson (CREEM, University of St Andrews, UK).*

## Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales

**Principal Investigators:**
**Susan Parks, Len Thomas**
**Project Status: Ongoing, 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 is coupling 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 highly endangered North Atlantic right whale (*Eubalaena glacialis*).

The visually verified acoustic data set 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.

> Results are being used to validate range-specific detection probability, false positive rates and cue (or call) rates for estimating acoustic density.

The project's approach is to collect visual survey data concurrently with acoustic recordings of vocally active right whales using a time-synchronized fixed PAM array. Results are being used to validate range-specific detection probability, false positive rates and cue (or call) rates for estimating acoustic density. Visual data are 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 is focused within a 3 km radius area from the survey platform. The visual observation team detects, localizes and tracks all right whale groups within that observation area.

Acoustic data are being 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, help to determine if sounds come from outside or inside the visual detection area. For example, whales calling offshore are 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 include acoustic animal-borne tag (DTAG-3/DTAG-4) attachments on suitable weather days and focal follows and acoustic tracking of whales within the acoustic array. Density estimation is focused on two cue types (all calls and contact calls).

The effective detection area estimates will be explored through three approaches:

1. **Spatial Capture Recapture (SCR)**
   This will be the primary approach for estimating the effective detection area. It relies 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 will be used to make more accurate inferences.
3. **Acoustic model-based assessment of effective detection area (EDA)**
   This will be based on published values for right whale call source levels and acoustic propagation modeling. The EDA estimates will be validated using visually tracked animals.

Finally, the visually obtained density estimation of right whales in the bay will be 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 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 theodolite, totaling almost 92 hours of visual data. Data analyses, including synchronizing acoustic data and acoustic signal detection and hourly density counts from the visual survey, were underway in 2021.

Southern right whales.

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 the 2021 PAM array data were completed and analyses of the 2022 array data were almost complete. One manuscript from the work was published in 2022 (see Publication sidebar for citation).

This validation work will allow scientists to better assess the application of different PAM density estimation approaches for right whales.

Work in 2023 will focus on completing analyses of the 2022 data, estimating cue rates and acoustic densities, comparing acoustic and visual density estimates, and preparing manuscripts for publication.

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 right 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.

At the completion of this study, visual survey data collected under the project will be contributed to the OBIS-SEAMAP online database, and tag data to the Movebank data repository. Results from this study will be shared with the ACCURATE project.

### 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.

## 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**

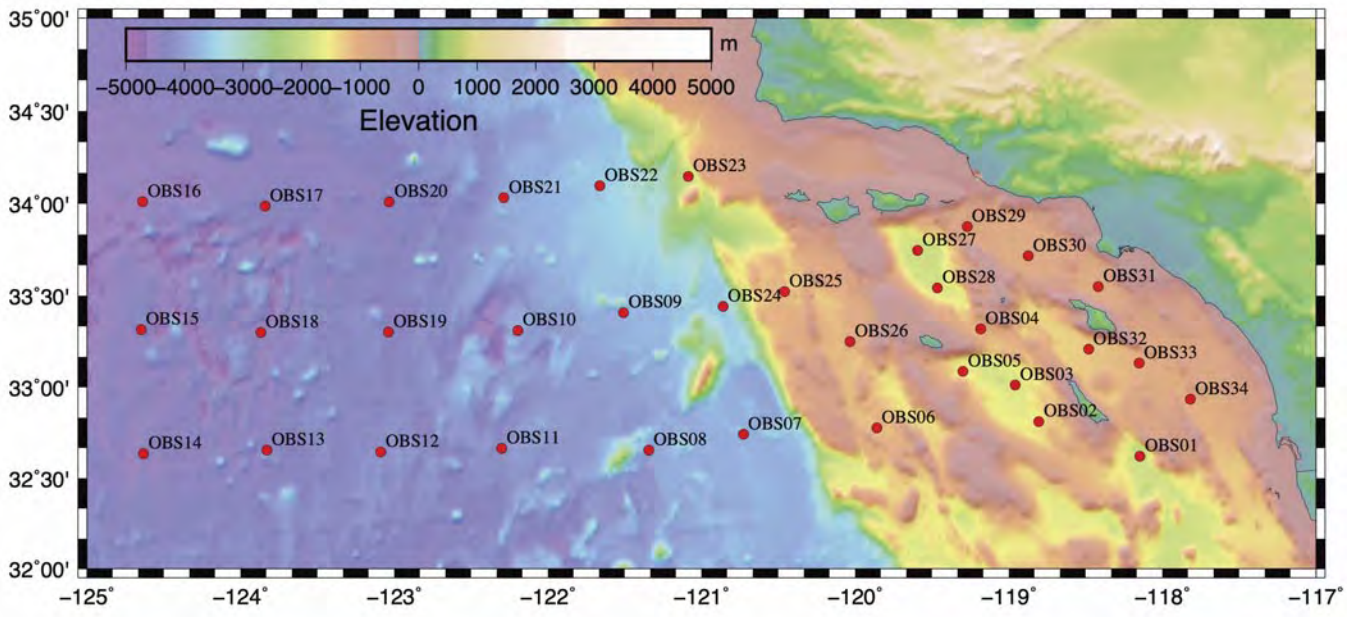
### NEED

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

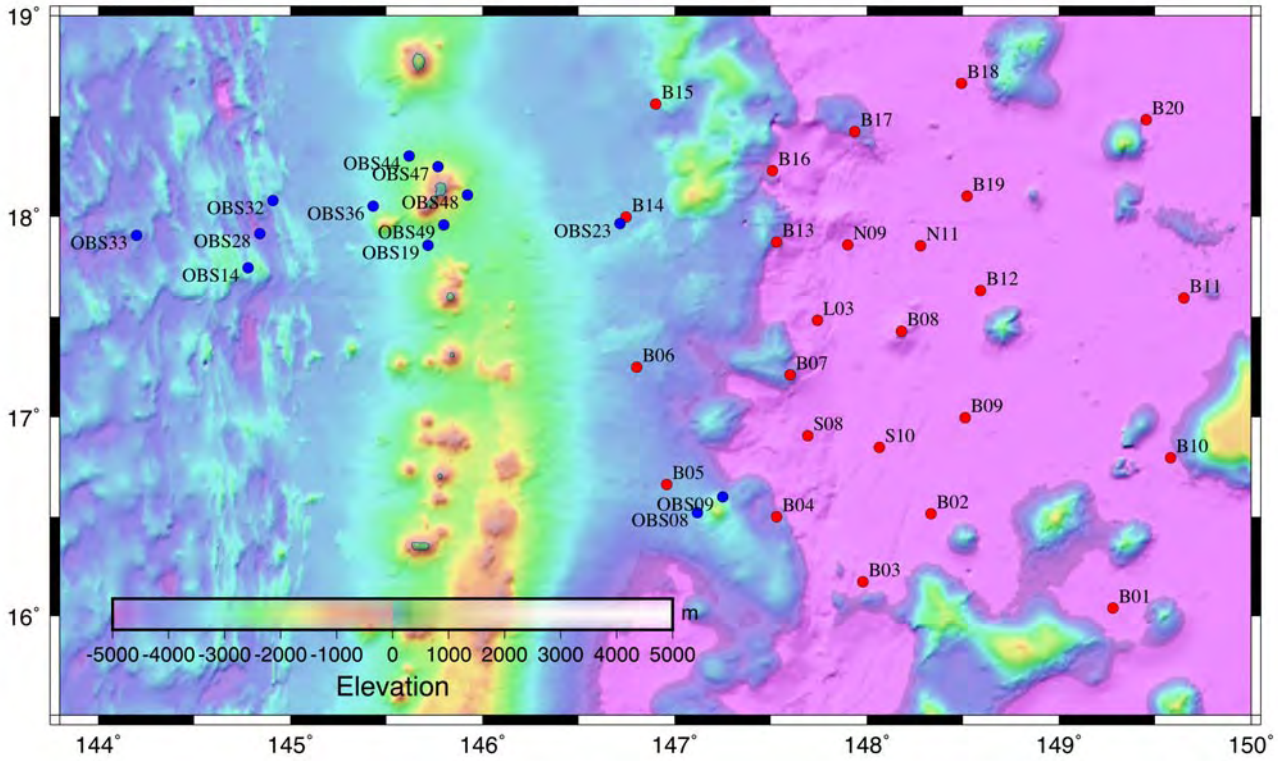
Marine mammal density estimates are a critical input for the Navy's acoustic effects modeling using the Navy acoustic effect model (NAEMO). Although the ship and aerial visual surveys traditionally used to estimate marine mammal density are viable for the Navy, such surveys are limited in spatial and 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 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 mate-




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.




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.

rials 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 data sets from around the world, selecting a set of case study data sets 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 data set.

The first part of the LMR-funded portion of the project will focus on signal processing of the OBS and CTBTO IMS case study data sets and implementing the density estimation methods developed under ONR funding. An additional task under this phase will include analyzing the case study data sets 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 data sets 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

Blue whale.
*Jess Morten, NOAA*

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 techniques being demonstrated will potentially make available extensive data sets reflecting large geographic areas at relatively low cost.

The project began with the ONR MMB-funded task of comparing ranging methods. The work in 2022 included identifying and processing case study OBS data sets and comparing ranging methods. In preparation for the upcoming LMR-funded tasks, the team solicited feedback from ONR and LMR on preferred CTBTO data sets to be processed beginning in 2023. The team will begin with the Wake Island CTBTO data set in the Pacific.

Other work in 2023 is expected to focus on density estimation methods under ONR funding and to initiate the LMR-funded signal processing tasks.

The techniques being demonstrated through this project will potentially make available extensive data sets 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).

# New Start Projects

## Bryde's Whale Cue Rates and Kinematics

**Principal Investigator: Tyler Helble**
**Project Status: New Start, 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 effort will develop information needed to determine the feasibility of using animal cue rate (calling rate) and the cue stability for acoustic density estimation. The project team at Naval Information Warfare Center (NIWC) Pacific will modify and apply passive acoustic monitoring (PAM) tools that they previously developed to capture long-term recordings (from 2011–2022) from Pacific Missile Range Facility (PMRF). The work will focus on determining the animal cue rate and the cue stability of Bryde's whales (*Balaenoptera edeni*). Tracking kinematics (swimming behaviors) will also be analyzed and reported. Because the swimming behavior of Bryde's whales is poorly understood, the additional data on this species' movements will help inform models that require such information (e.g., ship-strike risk and sonar exposure models).

The team will apply their PAM tools to PMRF data sets that span a decade to investigate the vocalizations and cue rates of Bryde's whales and to compare the cue rates over time and kinematic behavioral state. Work will include manually validating Bryde's whale calls previously identified in the data sets. The results from the analyses will also be compared to published cue rates to assess stability over time, location or population. The track kinematics will be examined against environmental variables such as time of year, season, wind and wave data, and against other situational data (such as distance to the nearest calling Bryde's whale).

Bryde's whale.
*Wayne Hoggard, NOAA*

Bryde's whale.
*Adam U, NOAA*

Additional analyses will include trying to identify various Bryde's whale call types. Currently, only one call type has been attributed to Bryde's whales at PMRF, but others may exist. Call types and calling rates will be compared against Bryde's whale calls found in other regions. If the cue rates from different regions are similar, it will increase confidence that these and other previously estimated cue rates can be broadly applicable.

> Understanding Bryde's whale vocalization and movement behavior will also help the Navy to better understand the group that spends time at PMRF.

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 LMR Project 62, Raven-X: Enhancing the Efficiency of Large-scale Bioacoustic Analyses, page 96.)

Work in 2023 will focus 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 in the area of a focal animal). A manuscript on kinematic and vocal behavior results is expected by early fall 2023.

If results from this work determine that a cue rate can be established for Bryde's whales and the rate remains stable, then this can be used to calculate animal density for this species from passive acoustic monitoring data. Understanding Bryde's whale vocalization and movement behavior will also help the Navy to better understand the group that spends time at PMRF and how that is related to other Bryde's whales in the Pacific. All this information can support environmental compliance assessment monitoring for Navy ranges.

### 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.

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

**Principal Investigator: Kaitlin Frasier**
**Project Status: New Start, 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 data sets includes consolidating the data sets, ensuring metadata integrity and physically transferring these data sets 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.

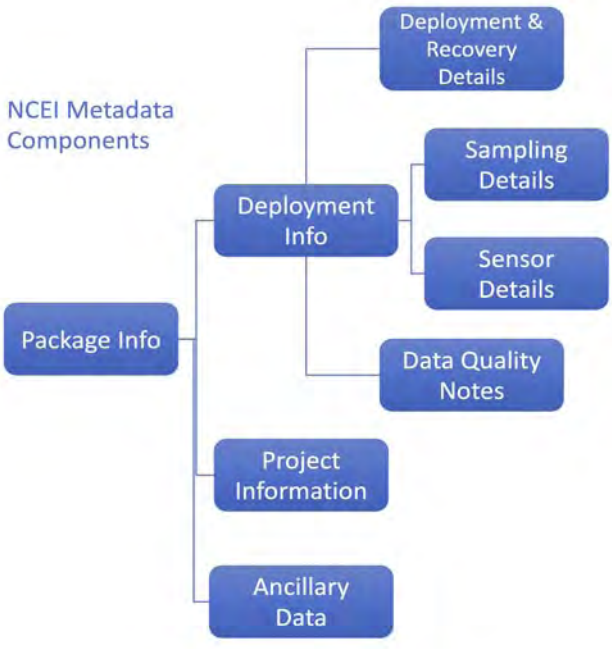
The project is focused on two core tasks: archiving data and participating in a case study project that is part of the Sound Cooperative (SoundCoop), also called the Passive Acoustic Monitoring National Cyberinfrastructure Center.

**Data Archiving**

The project team will archive some passive acoustic recordings from a 10-year time series recorded across up to ten simultaneous stations in the Southern California bight from 1999–2009. Some extended-duration recordings from Arctic, Antarctic and Gulf of California monitoring sites will also be included. In addition, the team will be working on a 15-year (2004–2019) time series of short-duration sonobuoy recordings associated with quarterly CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruises.

Efforts will include coordinating with Navy entities to ensure that the data sets are publicly releasable and coordinating with NCEI staff to ensure that the data are correctly formatted. The team will also

- Aggregate documentation that describes the equipment used, calibration information, deployment and recovery details, data quality and associated project details where appropriate
- Convert audio files from wave (WAV) and extended wave (XWAV) format to FLAC format, which achieves lossless 2x compression



- Generate Long-Term Spectral Averages, used to summarize the data visually at a high level.

### Case Study Project

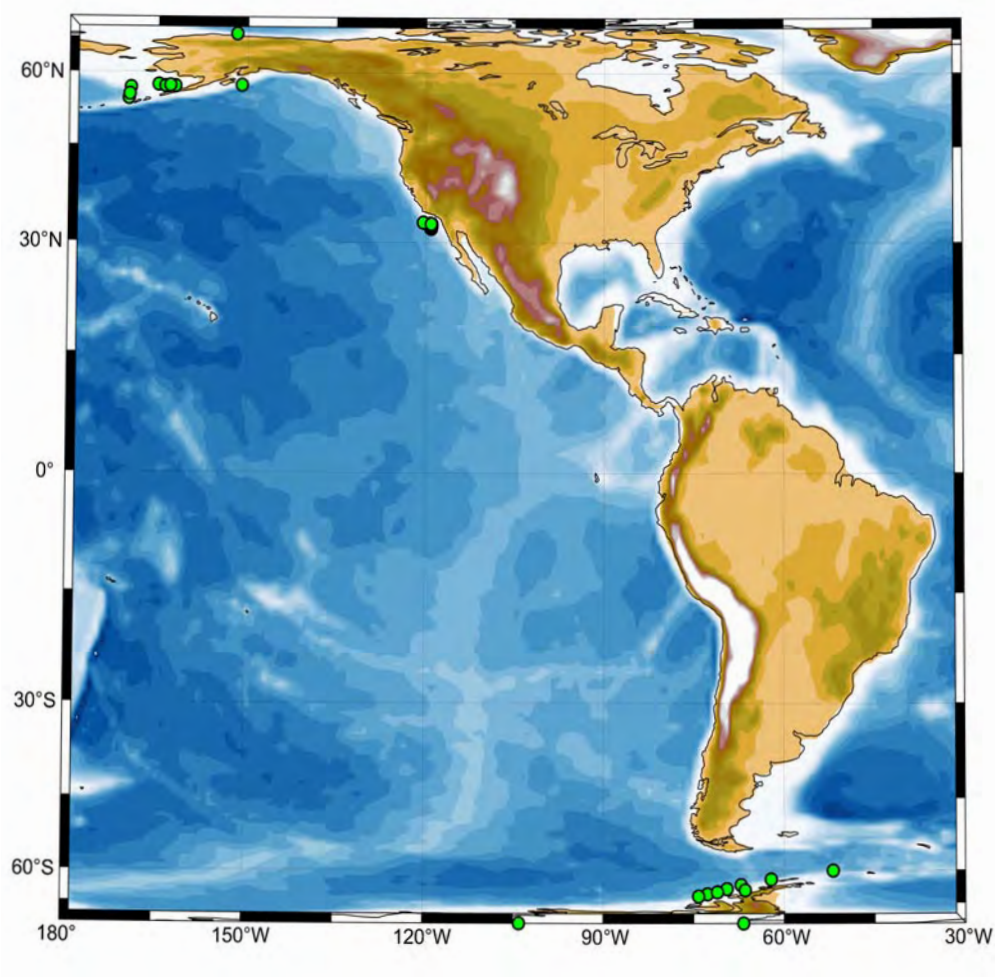
The project team will participate in a case study project, under SoundCoop, to conduct a temporal analysis examining change of sound levels in the Pacific and Arctic Oceans. The case study will use HARP and ARP data sets in conjunction with Noise Reference Station and Alaska Fisheries Science Center data.

Within its role in the case study, the project team will

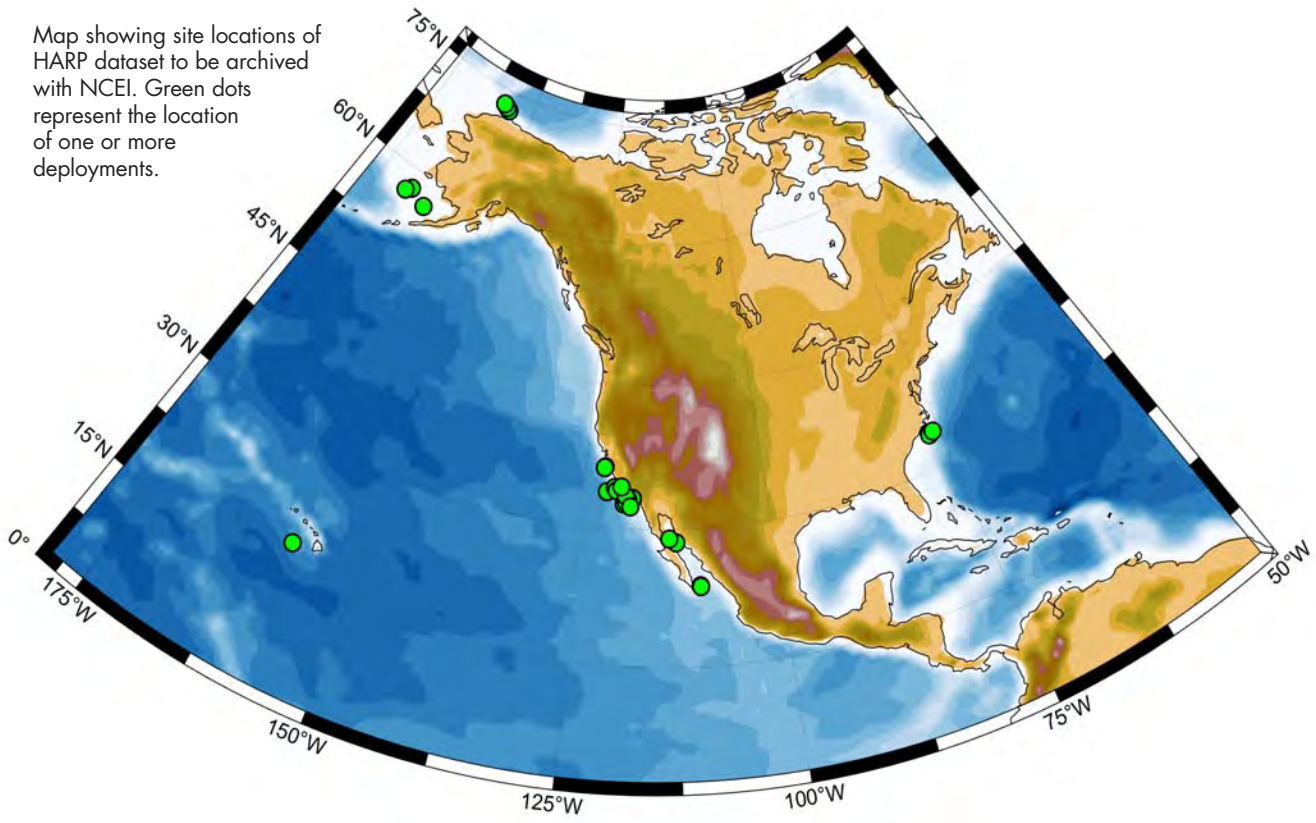
- Identify the best data sets to include in the case study
- Create and share calibrated sound levels for those data sets
- Provide expert insight on the sound level patterns to ensure accurate interpretation
- Participate in an annual one-week workshop in at NCEI in Boulder, CO over the course of the project.

The project will produce compressed (lossless) acoustic recordings organized with all relevant metadata including deployment information (e.g., site locations and depths, sensor design sensitivity and data quality information, and sponsor and project details) to facilitate further use. The project team will provide content and guidance to NCEI, which will develop web access to the acoustic data and/or metadata records.

During 2022, the project acquired necessary hardware to store the consolidated data and tested software packages that could be employed in the case study project. The project lead initiated other tasks including extracting archived data, aggregating and sending 140 terabytes (TB) of WAV data to the Navy security screening team, and clarifying metadata transfer methods and aggregation. Most project tasks will be performed during 2023, with project completion expected by the end of December.




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.

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

Archiving these data will protect past Navy investments in passive acoustic monitoring and will preserve 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 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**

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 data sets 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 preparation, documentation and archiving of acoustic challenge data sets related to Detection, Classification, Localization and Density Estimation (DCLDE), a biennial workshop focused on comparable methods for acoustic analysis on shared data sets. 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: New Start, 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 will enhance the shared software package, Raven-X, 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 data sets.

> The project will develop computer code to integrate existing acoustic detection, classification and location algorithms into Raven-X.

The Raven-X development team will work to integrate multiple custom algorithms currently

Humpback whale.

used by the Naval Undersea Warfare Center (NUWC) and the Naval Information Warfare Center (NIWC) Pacific.

The project will develop computer code 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. In addition, the LMR project, Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar (Project 34, page 37), has made significant progress on developing an improved sonar detector. As a case study, teams from that project and this Raven-X project have worked together to complete detector classification testing that was being conducted with a cooperative Navy/NOAA project, SanctSound (see LMR Project 34 for case study summary). Additional case study applications of Raven-X will be investigated as they present themselves.

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

To promote use at both locations and to build on work to date, this project will bring the products together for broader use within the Navy's marine mammal monitoring efforts. Work will include developing application programming interfaces (API) to support Raven-X processing capacity for Navy range sound and archive data sets. It will develop interfaces to enable existing algorithms that were written by NUWC and NIWC to be used together on the Raven-X platform. The common platform will provide new capabilities to each facility for processing and analyzing data from the Navy ranges. Key software applications will be tested and documented to facilitate use by Navy personnel.

The project will ultimately provide the Raven-X Toolbox for NUWC's M3R (Marine Mammal Monitoring on Ranges) and NIWC's WARP (Whale Acoustics Reconnaissance Project) programs. It will include documentation and training for Navy personnel. It will work to integrate multiple custom algorithms currently used by NUWC and NIWC Pacific to increase speed and efficiency of processing. Because Raven-X can be used on both laptops and large, distributed servers, it is expected to provide a low-cost and efficient distributed processing solution to handle Navy data sets previously too large to tackle.

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, which NUWC has 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: New Start, 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 SMART SEED Grant program using M3 data to analyze behavioral responses 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 data set 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)**

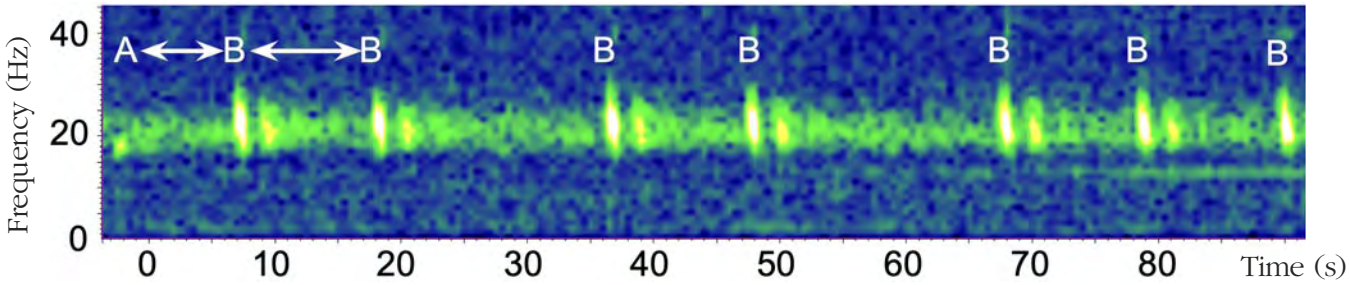
  The analysis focuses on segmenting the passive acoustic tracks into regular intervals and categorizing each interval into a behavioral state based on speed: fast or slow. The behavioral state will be modeled as a function of time of day, relative position of the seismic vessel and air gun status (on 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 data set 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, Developing Tools for Acoustic-only Behavioral Response Studies at Navy Instrumented Ranges.)

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

Fin Song Analysis




Fin whale.

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 will turn to task 2, analyzing M3 data to estimate Atlantic Fin Whale cue rate.

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

Project outcomes will include a process for securely handling and analyzing data from the M3 system. Two manuscripts are also anticipated from this project, one discussing behavioral responses of whales to seismic air guns and the other providing fin whale cue rate results.

The project will help to refine methods 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.

## 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 one ongoing project and three new start projects.

The ongoing project is

1. Project 41—Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags.

The new start projects are

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

*MC3 Nicholas Avis*

## Ongoing Project

### 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 re design 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.

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

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 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 ceased and work 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

Pilot whales.

Cuvier's beaked whales.
*Adam U, permit 15330*

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 rod, followed by simulation tests.

Field tests planned for 2023 include a repeat of the Phase 2 field tests of Design 1 with pilot whales in Hawaii and field tests in Southern California on fin, blue or beaked whales.

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 & 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, co-principal investigator, is a research biologist at the Foundation for Marine Ecology & Telemetry Research. He has been studying marine mammals for 18 years with much of his research focused on telemetry studies and deploying a wide variety of tags. His most recent focus has been using remotely deployed satellite tags to study beaked whale ecology and behavioral responses to anthropogenic sources of sound. Greg earned his geology degree from Colorado College.

## New Start Projects

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

**Principal Investigator: Alex Shorter**
**Project Status: New Start, 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 recently completed LMR Project 27 (see LMR 2021 Annual Report, available on the LMR website, 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.

Work will fall into three key tasks:

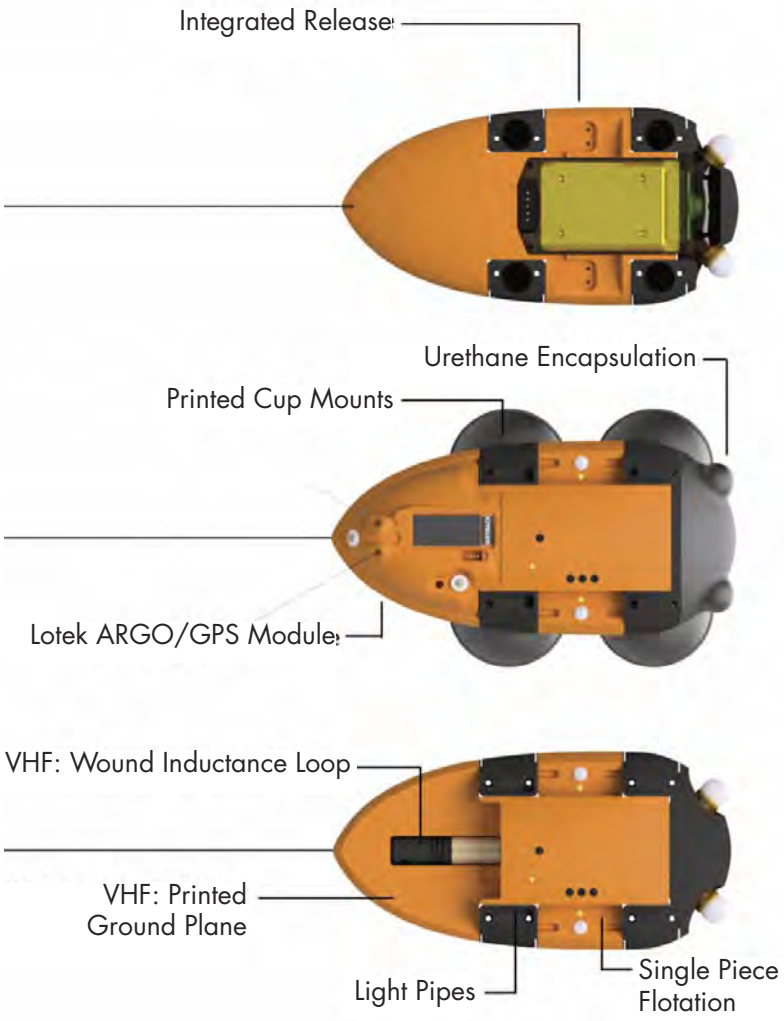
1. **Next generation tag integration**

   The next generation low-power tag electronics (DTAG-4) will be used to enhance the performance of tags in the lease pool tag system. Because the new and smaller electronics will affect multiple sub-systems of the tag package (e.g., floatation, VHS/GPS tracking, hydrodynamics and suction cups), this task is focused on engineering designs to accommodate the sub-system changes, system prototyping and system testing to evaluate the new designs.

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

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

During 2022, the project team initiated its engineering review and prototype design efforts. In 2023 the team will fabricate prototype tags for lab testing and field tests with humpback whales. An iterative process of testing and refinement will continue through field tests in 2024 and 2025.

Up to twelve units are expected to be built over the course of the project to support all testing. Data from the field testing will be used to define performance specifications, identify limits of tag performance and improve all elements of the tags and subsystems.

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: New Start, Project 57**

### NEED

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

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

### PROJECT

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

The project efforts are focused on six key DTAG capabilities:

1. **Data quality**

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

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

   Make and test changes to the goniometer antenna receiving system, the noise filtering systems in the antenna and the transmit ARGOS 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.

Mixed-DTAG+ successfully attached to a male killer whale in Iceland in July 2021, using the aerial remote tag system (ARTS).
*Nikolai Xuereb, Icelandic Marine and Freshwater Research Institute permit*

4. **Suction cup retention times**

   Evaluate retention characteristics of different configurations of suction cup sizes and materials developed under LMR Project 21 (e.g., existing mixed-DTAG+ and integrated DTAG).

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).

> Project efforts will provide critical validation of and improvements to technologies supporting multiple Navy-funded marine mammal research and monitoring projects.

Work is beginning with the mixed-DTAG+ and results from the mixed-DTAG+ trials will then be used to improve design plans for the integrated DTAG. DTAG core units and integrated DTAGs will be provided by collaborators at the University of Michigan. The team will test iterative versions and conduct on-animal field tests of the full suite of tag capabilities and will work with colleagues at the University of Iceland to use the resulting data to improve our understanding of the natural behavior of killer, humpback 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.

Work planned for 2023 includes redesigning the mixed-DTAG+ with a new core unit, GPS-ARGOS functions and video logger capabilities. Tags will be tested during a field trial in Iceland. The project team will also perform new tests of GPS-ARGOS signal reception by the goniometer.

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. A smaller version of these suction-cup attached tags will also extend tag use to smaller animals (e.g., young killer whales), increasing the range of animals that can be studied within behavioral response studies. 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 BRS 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: New Start, 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 will assess the functionality and durability of SonarPoint, which is 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 a configuration of multiple recorders to detect and locate underwater sound. Project efforts will focus 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.

The initial deployment will be a subset of three, week-long moorings that vary in depth and inter-recorder distance. It will focus on how recorder spacing affects localization results and will determine a maximum available recorder spacing. It will measure the distance at which cetacean vocalizations can be detected across all recorders and the effective range of a synchronization pinger.

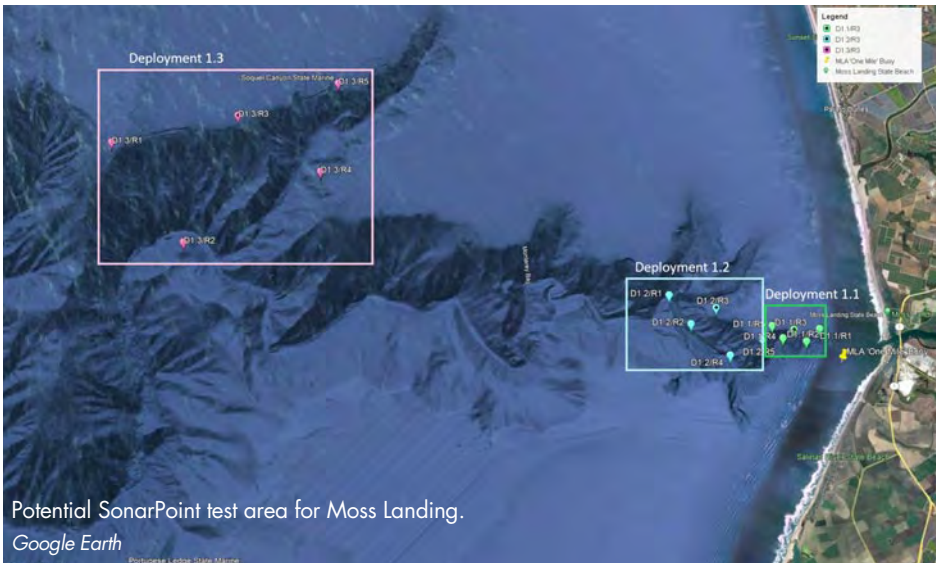
The second deployment is planned to demonstrate the long-term operation of the SonarPoint system and extensively evaluate the localization capabilities for a wide range of cetacean species. The array will be deployed at 1,000-2,000 meters for a long-term deployment.

The third and 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.

SonarPoint mooring string.
*Desert Star Systems*

Project analyses will use PAMGuard, an open-source passive acoustic software designed to detect and localize marine mammals. PAM-

Guard (version 2.02.03) will be used both to annotate the data set for marine mammal calls and to obtain localizations to these acoustic events. PAMGuard capabilities will be augmented by Desert Star-designed experimental software to explore the merits of different approaches to sound source localization.




Potential SonarPoint test area for Moss Landing.
*Google Earth*

The project's first deployment is scheduled for spring 2023, with subsequent deployments slated during fall 2023 and 2024. Analyses and reporting will be conducted after each deployment, with a final report completed by summer 2025.

> 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.

In addition to the final report, the project team will also provide the SonarPoint test system equipment and will produce a SonarPoint Sparse Array User's Guide and software to support system operation, signal detection and localization with SonarPoint.

This effort could ultimately support acoustic-based estimates of density, abundance and location of vocalizing marine mammals, specifically in locations beyond established Navy training ranges. The time-synchronized recorder array and software capable of handling large acoustic data sets 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 Jacobsen (independent contractor).*

## 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 data sets. 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, as well as establishing metrics for reporting performance of data analysis methods.

The one ongoing project in this section is

1. Project 46—Tethys Capability Enhancements.

*MC3 Nicholas A. Russell*

## 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 is enhancing Tethys, a workbench and standardization scheme for archiving and using acoustic metadata. Tethys offers researchers and mitigation specialists a method to record these data in a manner that can be preserved over long time periods and accessed from a variety of platforms such as web browsers, MATLAB®, Java, Python and R.

The prior version of Tethys was developed under a previous LMR project (Project 18), which was 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 following five key enhancements. Each is summarized below with its purpose, work done in 2021 and updates on work performed during 2022.

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). Recent 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.

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. One method to accomplish this consists of writing a text document to associate DCL and Tethys data fields. User feedback has indicated that new users want a simpler method of doing this. The project team worked during 2022 on performance testing of a system that greatly simplifies this process. A web-based interface displays the Tethys fields and sample DCL inputs

from databases, spreadsheets, etc. Users associate fields by dragging Tethys names onto the sample DCL data fields. Several data transformations are possible, such as combining multiple DCL fields (e.g., date and time), providing default values and specifying mathematical operations on the data (e.g., unit conversion).

The interface provides a summary of fields that have been matched as well as mandatory fields that are missing. In 2023, the team plans to enhance this with a software agent that offers advice, such as suggestions on potential matches for common non-standard data field names.

3. **An advanced mapping interface**

   The project is migrating from the current proprietary Google Maps application programming interface to the open-source Leaflet map library. During 2021, the team began designing a new Leaflet interface and will be leveraging current environmental data retrieval capabilities to generate mapping layers. Major portions of this were completed in 2022 (Figure 1 and Figure 2). The interface provides multiple views of data, ranging from showing where equipment is deployed to DCL effort and results. Environmental overlays for day and night as well as lunar illumination have been added.

   This switch to Leaflet provides the capability to add layers on existing web client maps to provide improved functionality over what can be implemented with the current Google Maps interface. It will support overlaying oceanographic and atmospheric data (sea surface temperature, wind, etc.) onto animal detections, and when applicable, the ability to show the evolution of these data over time.

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 work on entering 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 being addressed with the data import tool.

5. **Responsive help and enhancements to address user needs**

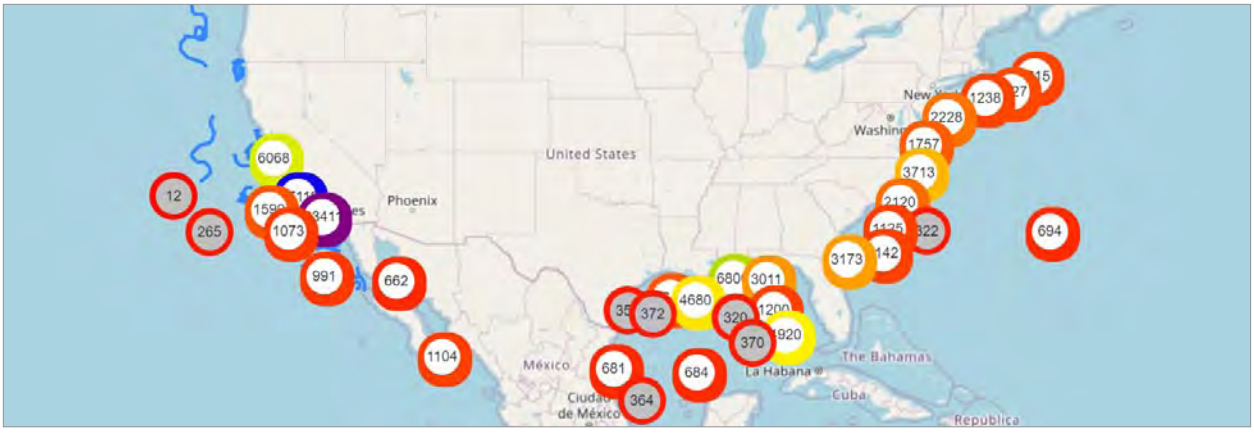



Figure 1: Map of instrument deployments. Circles represent fixed recording platforms with the number of days of recording shown inside the bubble. Gray bubbles represent single deployments, while white bubbles represent clusters of multiple deployments. Mobile instruments are represented by lines that show the instrument track.

*Data courtesy of Scripps Institution of Oceanography MBARC labs and NOAA Southwest Fisheries Science Center*

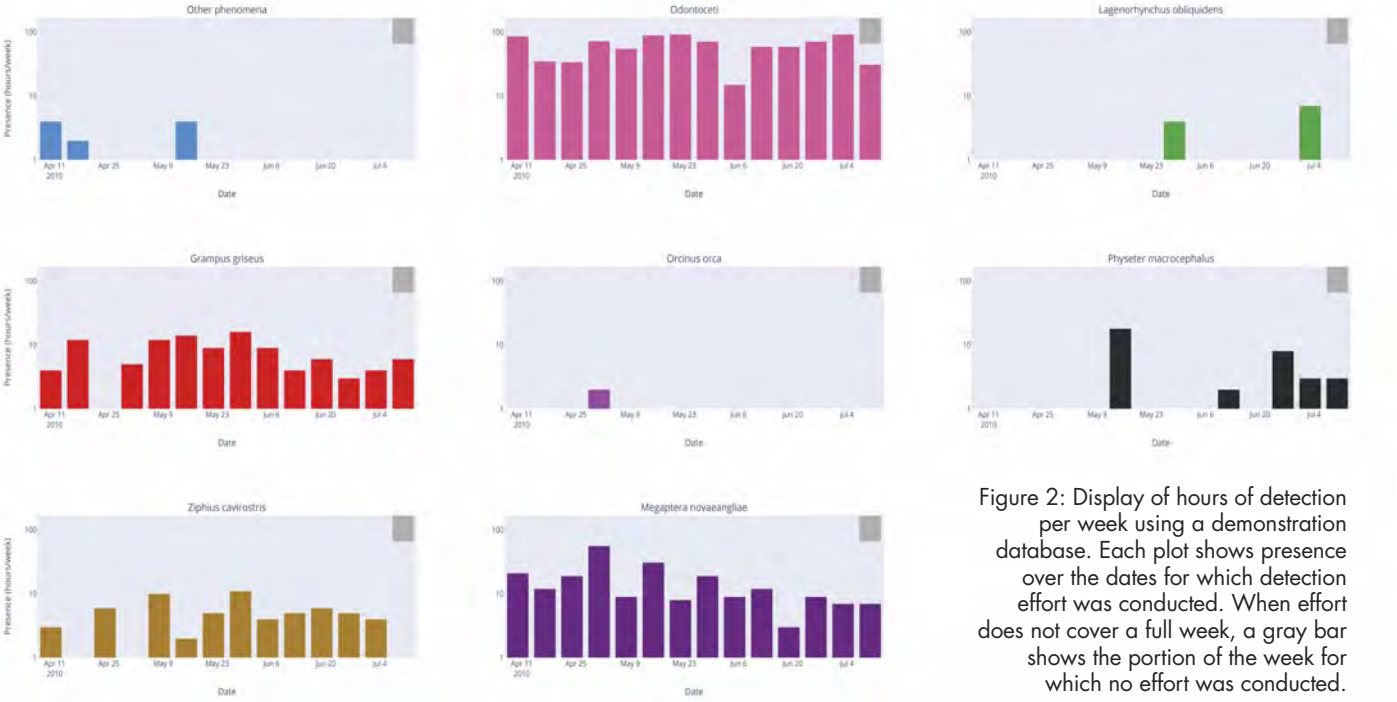



Figure 2: Display of hours of detection per week using a demonstration database. Each plot shows presence over the dates for which detection effort was conducted. When effort does not cover a full week, a gray bar shows the portion of the week for which no effort was conducted.

Experience has shown that each user group can have specific data organization needs that are not currently addressed within the Tethys schemata or implementation. The project team will continue, within reasonable levels of effort, to provide necessary enhancements and training. The team also will remain alert to potential overlaps of needs among user groups to avoid duplication.

When this project began, some optional tasks were identified for consideration as the project proceeded. At the end of 2022, BOEM began funding one of the optional tasks: integrating PAMGuard and Tethys (maintained by the University of St Andrews and San Diego State University, respectively). The project team has identified how data will be translated between PAMGuard and Tethys, created plans for deriving data that PAMGuard does not collect, and started to develop interfaces between Tethys and PAMGuard to enable a seamless transfer of PAMGuard detection and localization data to Tethys. This work to integrate PAMGuard and Tethys will be beneficial to the Navy and the general user audience.

This project will help the Navy to retain long-term information about marine mammal species that is needed for Navy monitoring and mitigation plans. 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 detailed environmental impact assessments.

### About the Principal Investigator

Marie Roch is a professor of computer science at San Diego State University and is affiliated with Scripps Institution of Oceanography's Marine Bioacoustics Research Collective. Her interdisciplinary computer science work on the bioacoustics of marine mammals is internationally recognized. Dr. Roch holds a Ph.D. in computer science from the University of Iowa.

# 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 two ongoing projects in this section are

1. Project 35—Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources
2. Project 48—Collection of *in situ* Acoustic Data for Validation of U.S. Navy Propagation Models of Ship Shock Trial Sound Sources.

## Ongoing Projects

### Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources

**Principal Investigator: Peter H. Dahl**
**Project Status: Ongoing, 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 has been established to conduct a set of well-documented and calibrated underwater acoustic field measurements associated with explosive detonations near the water surface. It will include 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.

Due to COVID-19 pandemic restrictions and associated difficulties coordinating opportunities with Navy range testing, all planned field tests for both 2020 and 2021 were canceled, preventing any 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.

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

An example of a 10-pound explosive deployed at 10 meters.
*Keith Jenkins*

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 116), which the NAEMO group will be analyzing.

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

Other work in 2022 included the LMR program-led coordination among the University of Washington, the Naval Research Laboratory, NAEMO experts and a Navy explosive ordnance disposal team. During discussions, the group determined that the scaled range theory supports achieving the project goals with data from smaller detonations than originally planned. A field effort to measure the underwater acoustic field from explosive detonations near the water surface is now planned for summer 2023. The revised plan is to measure the underwater acoustic field from detonations, ranging in size from 10 to 40 pounds of C-4 explosive, near the water surface. Measurements will occur at five different locations spanning different depths and distances from the detonation site.

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. 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.

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

## 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: Ongoing, Project 48**

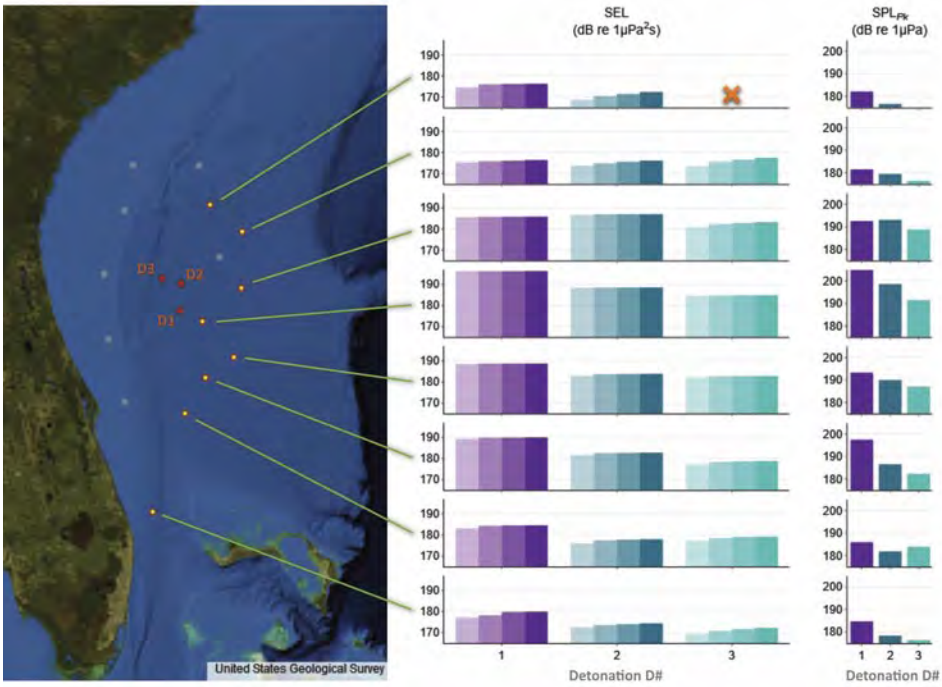
### NEED

**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 is 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 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).




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.

Recorders, including 15 moored autonomous recording devices (Rockhoppers) and six SoundTrap underwater acoustic recorders, 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.

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. Among other products, analytical results will be used to estimate the source level of explosions from each deployment location to generate impact volume maps. In addition, the team is seeking to analyze Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) data to calculate received levels at long distances.

The SoundTrap data are being analyzed for the presence of biological acoustic activity such as odontocete, baleen whale and fish sounds. These data also are being analyzed using the Before-After Control-Impact (BACI) methodology to estimate acoustical presence and behavior of marine species before and after detonations. In addition, the team is seeking prior years' data from other studies with nearby deployment locations to investigate how the rates of biological acoustic activity compare across years.

Work in 2023 will focus on completing data analyses, preparing manuscripts for peer-reviewed publication and writing a final report.

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

These *in situ* data will provide measurements of received levels and estimated source levels and spectra to support the Navy's efforts 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).*

# 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 2021, the allocation of sonobuoys available for research was cut. Thankfully, for 2022, our allocation of 480 sonobuoys was restored.

Projects and organizations receiving sonobuoys are

- California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys—University of California San Diego/Scripps Institution of Oceanography
- NOAA Pacific Marine Environmental Laboratory surveys—NOAA Marine Mammal Laboratory/ Alaska Fisheries Science Center
- Pacific Islands cetacean surveys—NOAA Pacific Islands Fisheries Science Center

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

Sonobuoy launch from the USS *Stout* (DDG 55). *PO3 Bill Dodge*

## 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 Auditory Evoked Potential 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 48 and 51, respectively. The third project—Investigating Bone-conduction as a Pathway for Mysticete Hearing—is being managed by ONR MMB. Fact sheets for each of these three projects are available on the LMR website under the SOST Partnership tab.

Minke whale.


FORECAST

Looking ahead, we anticipate even more accomplishments in 2023 and beyond. LMR will continue to focus on meeting the Navy's need for the tools and technologies to sustain at-sea training and testing within environmental permit requirements. We anticipate investing in a demonstration project for automated marine mammal detection technology for Unmanned Surface Vessel strike avoidance. This will be our first collaboration with the Navy's Unmanned Maritime Systems program to develop a technology for potential use on a Navy ship. We look forward to participating in this project and gaining more technology transition experience with Navy ships.

Looking beyond 2023, we anticipate investing in an appropriate simulated sound source for the planned SURTASS LFA behavioral response study, with Phase II field efforts expected sometime in 2025. In addition, we are strengthening our collaboration with NOAA and BOEM by co-investing in the expansion and continued development of a federal archive for passive acoustic monitoring data. Lastly, we will be discussing among Navy end users which priority research need topics LMR should consider investing in 2024 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 nine 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. LMR research will continue to directly support the Navy's ability to train and test at-sea and preserve core Navy readiness capabilities.

*MC2 Elliot Schaudt*

# Publications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*MC2 Almagissel Schuring*

# Acronyms and Abbreviations

**3S3** .....Sea mammals, Sonar, Safety project phase 3
**ABR**.....Auditory brainstem response
**AEP**.....Auditory evoked potentials
**ANSI**.....American National Standards Institute
**AN/SQS-53C**.....Computer-controlled surface-ship sonar
**ARGOS**.....A satellite-based system used for tracking data platforms (e.g., animal monitoring tags) in environmental monitoring
**ARP**.....Acoustic Recording Packages
**ASA** .....Acoustical Society of America
**BAA** .....Broad Agency Announcement
**BOEM** .....Bureau of Ocean Energy Management
**BRS** .....Behavioral Response Study
**CAD** .....Computer-aided design
**CAS** .....Continuously active sonar
**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
**DET**.....Detection error tradeoff
**DICASS** .....Directional command activated sonobuoy system
**DenMod** .....Density Surface Modeling (project)
**DTAG**.....Digital acoustic recording tag
**EIS**.....Environmental Impact Statement
**ESA** .....Endangered Species Act
**FM** .....Frequency modulation
**FSST**.....Full ship shock trial
**GPL** .....Generalized Power Law
**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
**LFM** .....Linear frequency modulation
**LIMPET** .....Low Impact Minimally Percutaneous External-electronics Transmitter
**LMR**.....Living Marine Resources
**LMRAC** .....Living Marine Resources Advisory Committee
**M3R** .....Marine Mammal Monitoring on Navy Ranges
**MARMAM**.....Marine Mammals Research and Conservation Discussion
**MFAS** .....Mid-frequency active sonar
**MMC**.....Marine Mammal Commission
**MMPA**.....Marine Mammal Protection Act
**MSM**.....U.S. Navy Marine Species Monitoring Program
**NAEMO**.....Navy Acoustic Effects Model
**NEPA**.....National Environmental Policy Act
**NAVAIR** .....Naval Air Systems Command
**NAVFAC EXWC** .....Naval Facilities Engineering and Expeditionary Warfare Center
**NCEI**.....National Centers for Environmental Information
**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
**OBS** .....Ocean Bottom Seismometers
**OBIS-SEAMAP**.....Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations
**OE**.....Opportunistic exposure
**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 (N4 predecessor)
**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
**RMS**.....Root mean square
**ROC** .....Receiver operating characteristic
**SBIR** .....Small Business Innovative Research
**SCORE**.....Southern California Offshore Range
**SCR** .....Spatial Capture Recapture
**SEL**.....Sound exposure levels
**SMRT**.....Sound and motion recording and telemetry
**SOCAL**.....Southern California
**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
**TWS** .....Traveling wave speed
**UAV** .....Unmanned aerial vehicle
**UUV**.....Unmanned underwater vehicle
**VHF**.....Very high frequency
**VLA** .....Vertical line array
**WHOI** .....Woods Hole Oceanographic Institution
**µCT**.....Computed microtomography

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