LMR 2025

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JUNE 2026

U.S. NAVY LIVING MARINE RESOURCES PROGRAM ANNUAL REPORT

LMR 2025

U.S. NAVY
LIVING MARINE RESOURCES PROGRAM
ANNUAL REPORT

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Headshots by Kenny Backer Photography and Teresa Marie Photography.

Most marine mammal photos that do not include a credit/permit number are from stock photo services.

INSIGHTS

Welcome to our annual update on the Living Marine Resources (LMR) Program. This report provides an overview of the valuable work performed by all LMR participants to support the Navy's ability to train, test and be mission ready. The Program Overview section (starting on page 6) summarizes how the LMR program supports Navy readiness and outlines how we coordinate with other Navy programs and federal agencies to increase program efficiency. These efforts have leveraged over $17 million of additional funding toward mutual benefit since 2014.

The Program Portfolio section (starting on page 16) includes background and updates on our many technical projects. In 2025, the LMR program was managing 22 projects, all carefully selected to meet specific Navy-defined priority needs. These projects include three projects that were completed during 2025, as well as 14 ongoing projects and five new projects.

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

Products from the completed projects are being delivered to the Navy end users and are contributing to Navy compliance. One of those completed (Project 50, page 17) investigated the loudness perception in killer whales, providing the data needed to modify predictions of behavioral and auditory impacts and accounting for the duration of Navy acoustic sources. A second completed project (Project 57, page 20) provided 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. The third completed project (Project 60, page 23) archived historic passive acoustic recording data with National Centers for Environmental Information (NCEI), ensuring that the Navy's investment in passive acoustic data will be preserved and made publicly available for future analysis.

Results from many of LMR's current and past projects continue to contribute to the scientific literature that provides critical, well-founded scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) planners, regulators, scientists and other stakeholders. Twenty-three citations for 2025 publications are listed in the Publications section of this report (page 94). A list of 209 publications issued from 2013 through 2025 is available on our website (exwc.navfac.navy.mil/lmr) under the Publications tab.

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

Anu Kumar, Program Manager

Mandy Shoemaker, Deputy Program Manager

OVERVIEW

Mission

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

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

NAVY READINESS DEPENDS ON COMPLIANCE WITH FEDERAL LAWS

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

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

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

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

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

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

NAVY PROGRAMS THAT ENABLE COMPLIANCE WITH FEDERAL LAWS

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

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

To promote ongoing coordination among all investments supporting compliance and permitting, the program manager from ONR MB, representatives from the MSM program and representatives that manage other related investments are members of the LMR Advisory Committee (LMRAC) (described on page 10).

The Office of Naval Research Marine Biology Program

The ONR MB program is the Navy's basic (6.1) and early applied (6.2) research program on marine species. This program provides robust, science-driven research to ensure Navy readiness while mitigating the potential effects of training and testing activities. Research topics include monitoring and detection tools, baseline ecology of species and the effects of sound on marine life. Results help to identify physiological, behavioral, ecological and population-level effects that are fundamental to meeting compliance requirements. 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 have high technical risk and long timelines.

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

The Living Marine Resources Program

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

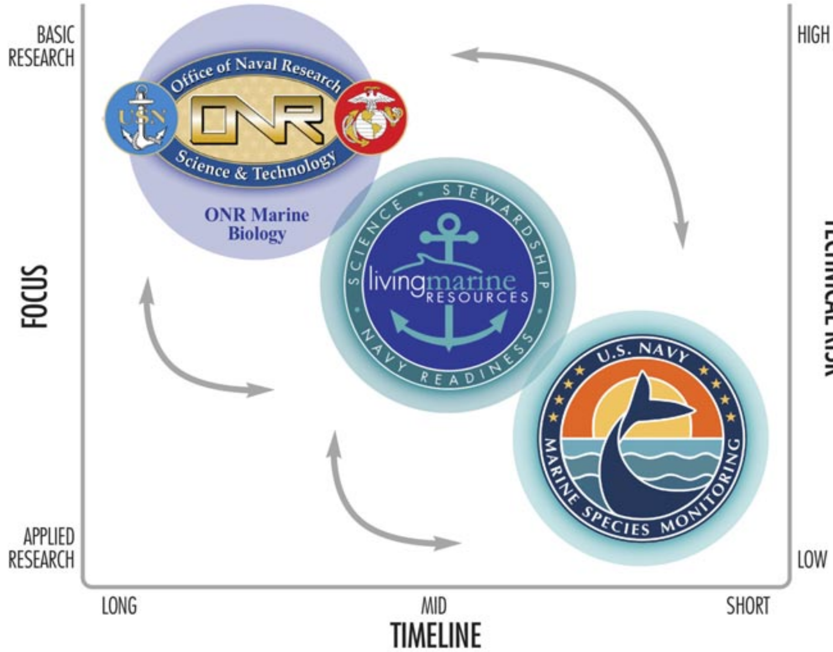
MC2 Tehya Delgardio-Lawrence

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 to

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

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

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



U.S. Navy Marine Species Monitoring Program

The U.S. Navy's MSM program is a legal 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 MB 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 MB project is deemed ready to move 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 compliance documentation. In some cases, when a technology or method is ready for application, it will be transferred directly from ONR MB development to the monitoring program.

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

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

STRUCTURE

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

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 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)

NAVCENT Public Affairs

- 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.

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 pathways to transfer solutions to end users.

Technical Review Committee

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

Program Office

The LMR program is managed by Naval Facilities Engineering and Expeditionary Warfare Center (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 research, development, test and evaluation (RDT&E) action officer. Among its many roles as program sponsor, OPNAV N4 provides the LMR program's annual funding, sets policy and guidance for the Navy's research priorities, approves the list of needs and authorizes new projects.

PROGRAM INVESTMENTS AND PROCESS

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

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

Program Investment Areas

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

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

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

2. **Data processing and analysis tools**

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

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

3. **Monitoring technology demonstrations**

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

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

4. **Standards and metrics**

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

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

5. **Emergent topics**

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

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

Lt. Drew Verbis

Navy Needs

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

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

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

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 announced on the LMR website. The solicitation includes instructions on submitting proposals through a Broad Agency Announcement for offerors that are outside the federal government. After the solicitation closing date, the proposal evaluation process—conducted by the LMRAC, TRC and program managers—begins with a review to identify those proposals of greatest interest. After the proposal evaluations are complete, the program manager makes a final recommendation to the program sponsor of projects to be funded.

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

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

MANAGEMENT AND COMMUNICATION TOOLS

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

Newsletters

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

Research Publications Spreadsheet

During 2020, the LMR program added a full listing of program research publications, in spreadsheet format, to the LMR website. At the close of 2025, the spreadsheet list included 209 publications, beginning in 2013 from the earlier Marine Mammal Research program, which preceded the LMR program's establishment. While the list focuses on publications resulting from Navy LMR funding, it also includes publications not specifically funded by the LMR program but that acknowledged use of data, methodology or technology developed with funding from LMR.

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

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

Project Highlights Fact Sheets

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

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

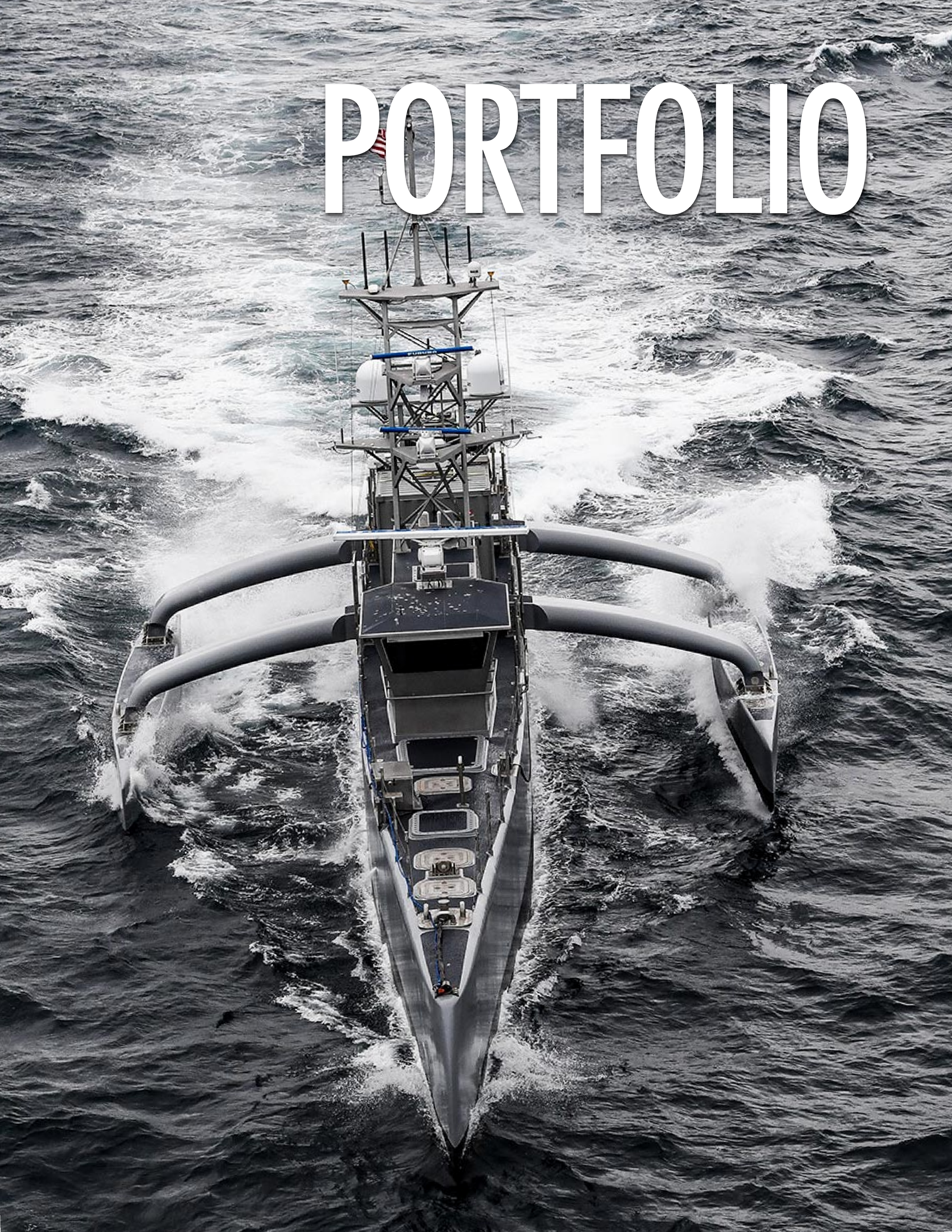
In-progress Review

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

LMR Website

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

PORTFOLIO



Completed Projects

Three projects were completed during 2025 and are summarized in this section. Results from these projects are now available for use by the Marine Species Monitoring program and those involved in at-sea compliance.

- Project 50—Loudness Perception in Killer Whales (*Orcinus orca*); Effects of Temporal and Frequency Summation
- Project 57—Demonstrating Suction-cup Tag Systems to Support Behavioral Response Studies
- Project 60—Historic ARP and HARP Passive Acoustic Recording Archiving with NCEI.

LMR Projects

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

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

NEED

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

PROJECT

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

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

Originally, the project scope included investigation of subjective loudness of short duration signals compared to long duration signals (number 2 above). However, the animals struggled with the training associated with this task and it became clear that the team needed to move in a different direction. Therefore, the decision was made to focus on the effect of masking noise on duration-dependent detection thresholds instead (number 3 above).

The project team worked with trained killer whales (*Orcinus orca*) with good species-representative hearing. Due to their large size and increased sensitivity to lower-frequency sounds, killer whales are currently the best "hearing surrogates" for other large odontocetes such as beaked whales and sperm whales, where high-quality behavioral audiograms do not exist. Testing was conducted at SeaWorld in a quiet and isolated pool that supports an exceptional amount of experimental control over the testing context and acoustic stimuli.

The work was ultimately organized around the following two experiments:

1. **Detection thresholds and response latency as a function of signal duration and frequency**
   The goal was to measure detection thresholds as a function of frequency for different duration signals in additional whale subjects.

Killer whales.
Robert Pittman, NOAA

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

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

Initial training and data collection efforts were started with two whales in 2021. A manuscript was published in 2022 that summarized previous work focused on the mechanisms of auditory masking (see the Publications sidebar for project publications).

In 2022, the project team completed experiment 1 data collection for the following frequencies: 1, 10, 20, 40, 80 and 100 kHz. A manuscript on this initial dataset focused on temporal integration of tone signals was published in 2023 (see Publications sidebar). Data collection for experiment 1 continued into 2023 and 2024, which included an additional frequency (5 kHz) and additional whale subjects. By the end of 2024, the above frequencies were tested over the following signal durations: 0.05, 0.1, 0.2, 0.5, 1, 5, 10, 50, 100, 200, 500, 1000 and 2000 ms. However, please note that not all frequency-duration combinations were tested for all whale subjects, and sample sizes varied. A manuscript focused on response latency of conditioned vocal responses was published in early 2025 (see Publications sidebar).

Data collection for experiment 2 began in 2023 and continued through 2025. This study was focused on collecting the necessary data to modify current auditory weighting functions to include duration and baseline ambient sound levels as modifying factors. Signal durations between 0.5 and 500 ms were tested at frequencies of 5, 40, and 80 kHz. However, please note that not all frequency-duration combinations were tested for all whale subjects, and sample sizes varied.

In 2025, for experiment 2, detection thresholds as a function of signal duration were tested at three frequencies (5, 10, and 20 kHz) for two additional whale subjects. It was important to verify the results of data collected in 2024 from one killer whale in additional subjects so that variability between subjects could be determined and to support future applications of the data.

This study provided necessary data to modify predictions of behavioral and auditory impacts to account for the duration of Navy acoustic sources. This new understanding of auditory perception as a function of signal duration in killer whales is applicable to other large odontocetes such as beaked whales and sperm whales. A manuscript is currently underway for experiment 2 and expected to be published in 2026.

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

This improves the Navy's modeling analysis that estimates how many animals may be affected, streamlining the compliance process.

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

About the Principal Investigators

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

Brian Branstetter is a marine natural resources specialist at Naval Facilities Engineering Command Pacific (NAVFAC PAC). He started this project when he was with National Marine Mammal Foundation, before moving to NAVFAC PAC, and continued 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 Hawai'i at Mānoa.

Publications

Stephens, J., Accomando, A.W., Nease, K., Branstetter, B.K. and Robeck, T.R. (2025). Latencies of conditioned vocal responses to hearing test tones in killer whales (*Orcinus orca*). *Frontiers in Behavioral Neuroscience*, 28. DOI 10.3389/fnbeh.2024.1495579.

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

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.

Demonstrating Suction-cup Tag Systems to Support Behavioral Response Studies

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

NEED

Marine mammal tag technology to collect marine mammal movement, diving and acoustic data was previously developed by the Office of Naval Research Marine 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 worked 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 focused on six key DTAG capabilities:

1. **Data quality**
   Systematically test DTAG core units to identify when failures occur and how to reduce their occurrence.
2. **Real-time tag tracking via GPS-Argos signals received by a goniometer (direction and distance estimation device)**
   Make and test changes to the goniometer antenna receiving system, the noise filtering systems in the antenna and the Argos transmit antenna to increase the reception range of tagged whales.
3. **Argos-aided tag recovery**
   Evaluate how possible changes to the Argos transmit antenna could affect Argos transmission once the tag is floated after detachment.
4. **Suction cup retention times**
   Evaluate retention characteristics of different configurations of suction cup sizes and materials developed under LMR Project 21 (Extended Duration Acoustic Tagging of Right Whales; completed in 2021).
5. **Additional sensors**
   Evaluate two additional sensors on the mixed-DTAG+: a small video logger to enable observations of the prey field encountered by tagged whales and a low-cost depth and acceleration logger as a backup device.
6. **Tag size**
   Create and test a smaller version of the current mixed-DTAG+ design for use with smaller animals (e.g., smaller killer whales and pilot whales).

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


Humpback whale tagged with a Mixed-DTAG during the 3S4-2025 sonar trial using the ARTS deployment system.
Norwegian Animal Research Authority tagging permit

The project achieved important progress and successes during 2023. Over the first half of 2023, efforts focused on designing an updated version of the mixed-DTAG+, specifically to include a newly designed wide-angle video and a 24-hour data logger produced by Little Leonardo. The updated version of the mixed-DTAG+ performed well during summer 2023 fieldwork in southern Iceland. The video-data logger captured high-quality depth and acceleration data for 24 hours as a backup to the DTAG core unit and recorded clear wide-angle video sequences revealing complex feeding and social behaviors of tagged whales. The goniometer system for GPS tracking of the tagged whales exceeded previous performance, reliably providing near real-time GPS locations up to 9 km away. Extra tag flotation improved Argos signal reception during tag recovery, and suction cup retention times averaged 15.9 hours with a maximum of 24.8 hours, including several deployments on smaller killer whales. Based upon this positive outcome, the mixed-DTAG+ was used successfully in the 3S4 behavioral response sea trial in Norway (LMR Project 64, page 31) in October 2023, demonstrating the benefit of this project to behavioral response studies.

Work during 2024 built upon the 2023 progress, with a successful summer 2024 trial in southern Iceland. The team field-demonstrated a free and publicly available PAMGuard module ('pamgonio') to plot tracks generated using the real-time GPS-Argos tracking system plus optional visual observations. Both the mixed-DTAG+ and the integrated DTAG were field tested during the Iceland fieldwork with longer attachment durations for the mixed-DTAG+ (22.8 hours), than the integrated DTAG (5.8 hours). Performance of the mixed-DTAG+ was strong for all other capabilities, and the mixed-DTAG+ was again used successfully in the 2024 field trial for LMR Project 64.

During 2025, the project's concluding year, the team completed several tasks and again contributed to other LMR projects. The team produced a final, fully enclosed mixed-DTAG housing, which was used by the 3S4 team (LMR project 64) during its October 2025 sea trial in Norway. This updated tag housing is compatible for use with both the existing DTAG3 core units and the new DTAG4 core units with release devices, which were received from University of Michigan. Because the DTAG4 core unit is smaller than the DTAG3 core, the housing includes a custom 'holder' that matches the form-factor of the DTAG3 core unit. The 'holder' is a soft plastic material that will also act as a shock absorber during tag attachments. The final version of the mixed-DTAG that was used during the 3S4 project trial collected nearly 290 hours of animal-attached data during the 3-week trial.

Results of these types of studies demonstrate and validate technology for use by the Navy's Marine Species Monitoring program.

Also in 2025, the automatic GPS tracking system developed under this project was tested under another LMR project. A project team member was invited to the University of California Santa Cruz to assist researchers on a pinniped behavioral response project (LMR Project 76—Evaluating Behavioral Responses of Pinnipeds to Mid-frequency Sonar to Support Navy Compliance Permits, page 46). The automatic GPS tracking system was tested on a pinniped in preparation for a controlled exposure experiment (CEE). The system worked well, providing good locations for tagged California sea lions. It is an important step that this system, which was developed for cetaceans, appears to work with a pinniped, enabling effective CEEs with other species.

This project has provided critical validation of and improvements to the mixed-DTAG+ and integrated-DTAG, which are significant technologies supporting multiple Navy-funded marine mammal research and monitoring projects. Results of these types of studies demonstrate and validate technology for use by the Navy's Marine Species Monitoring program. In addition, data collected using this technology are essential for Navy at-sea compliance efforts. The technology developed under this project is now available to the scientific community for future data collection 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 two decades of experience in cetacean research on various behavioral response projects. He holds a Ph.D. in biological oceanography from the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution joint program.

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

Publications

Bonhoeffer, S., Selbmann, A., Angst, D.C., Ochsner, N., Miller, P.J.O., Samarra, F.I.P. and Baumgartner, C.D. (2025). orcAI: A machine learning tool to detect and classify acoustic signals of killer whales in audio recordings. *Marine Mammal Science*, (e70083). DOI 10.1111/mms.70083.

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

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

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

NEED

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).

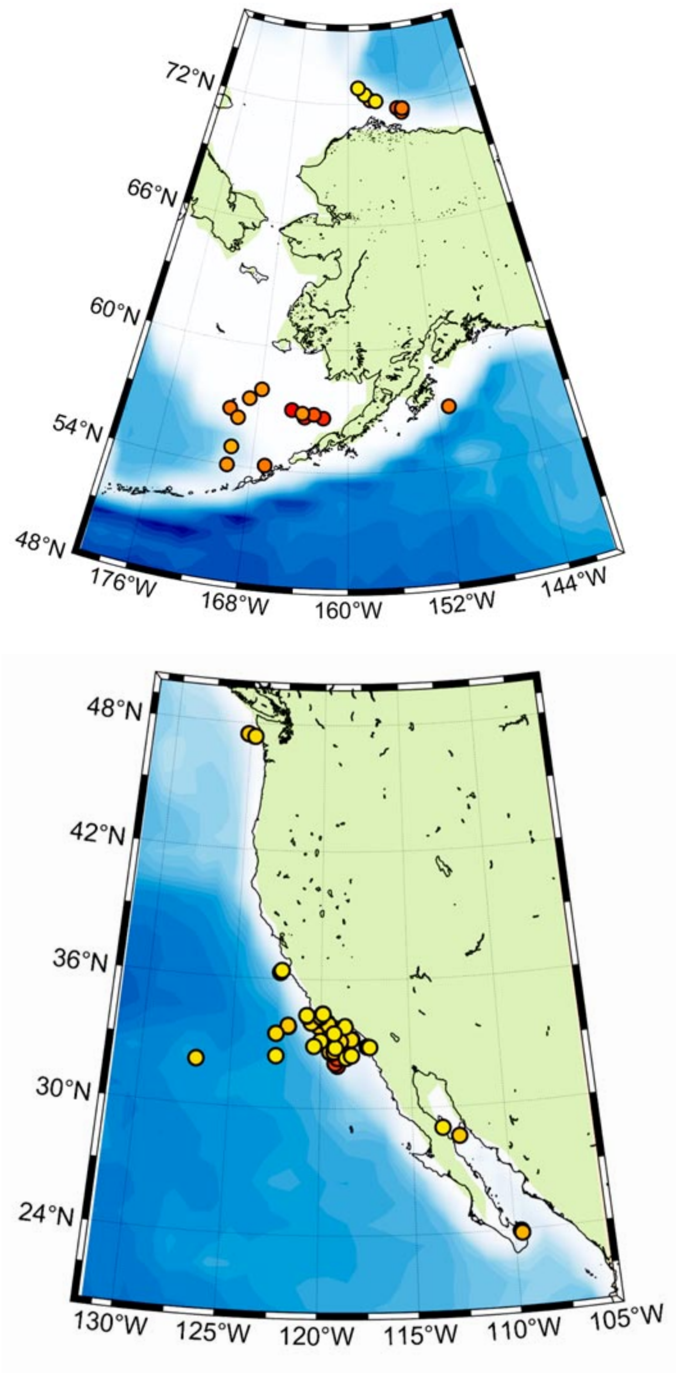
PROJECT

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 focused on preserving the oldest sets of ARP/HARP data, collected between 2003–2010. Archiving these datasets includes consolidating the datasets, ensuring metadata integrity and physically transferring the datasets to National Centers for Environmental Information (NCEI), which has been working to preserve passive acoustic monitoring data and make them publicly accessible for future analysis. The project team collaborated with Navy entities and NCEI staff to develop and streamline archiving processes to improve the feasibility of future archiving efforts.

The project focused on two core tasks: archiving data and participating in a case study project that is part of the Sound Cooperative (SoundCoop), also called the Passive Acoustic Monitoring National Cyberinfrastructure Center. (For information on a related project, see Project 66 on page 60 of the LMR 2024 Annual Report.)

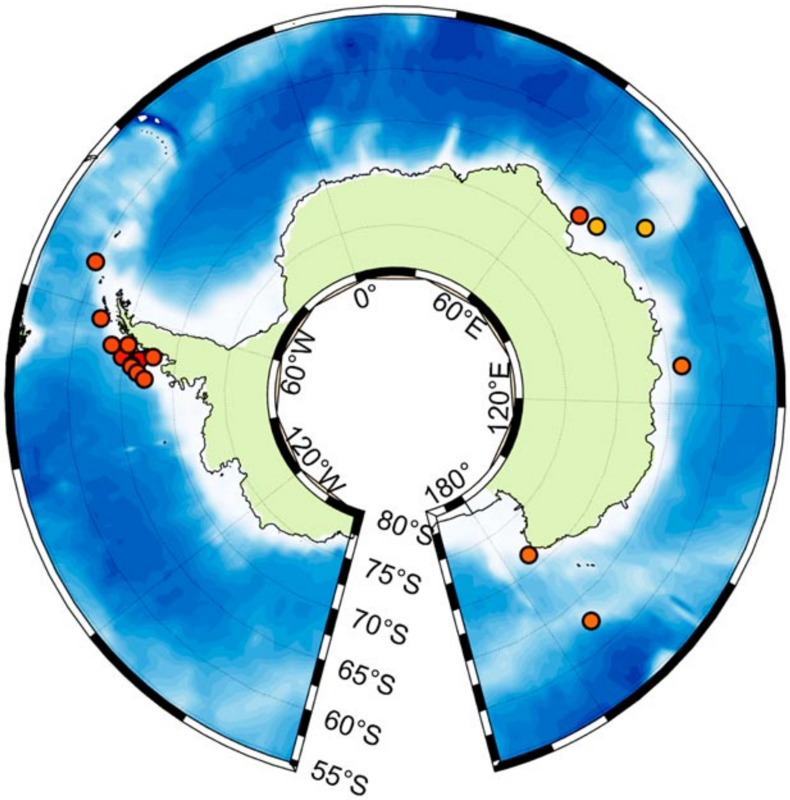
1. **Archiving Data**

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



Alaska and West Coast locations.

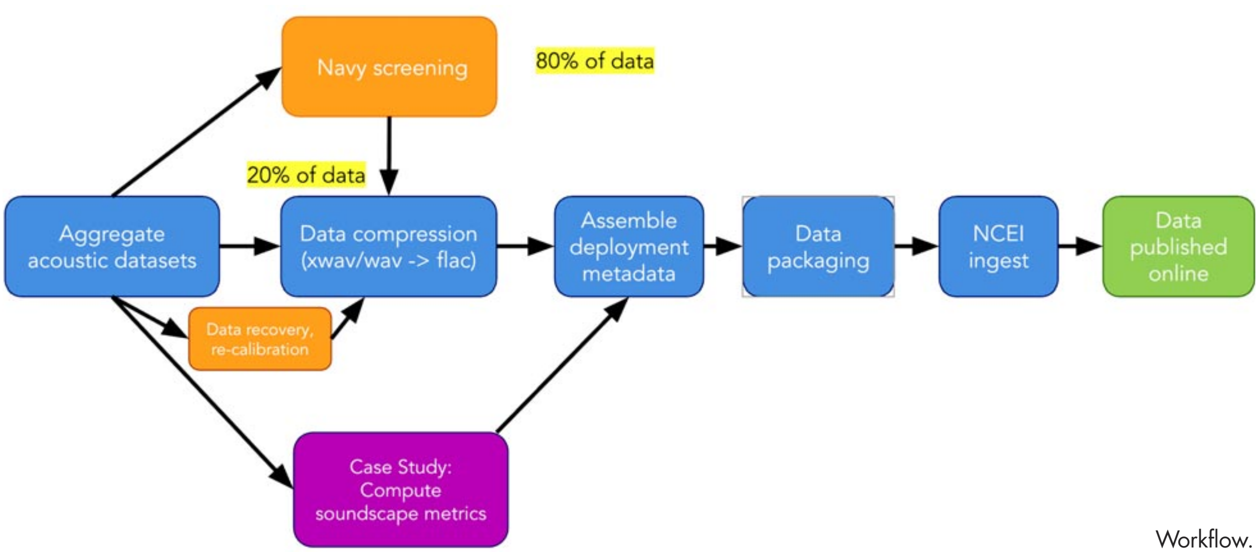
could move forward with setting up a process to archive this data.



Antarctic locations.

In 2023, in coordination with NCEI software developers, a programmatic workflow tool "PassivePacker" was developed to automate the process of compressing and packaging acoustic datasets for the NCEI archive. Three test packages not requiring security screening were packaged using this tool and shipped to NCEI, where they are now publicly discoverable online. Once the test packages were successfully archived, the team used the established process to package and submit to NCEI the remaining data that did not require screening. This included a portion of the HARP data and sonobuoy data collected during 2004–2024 CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruises. The portion of data that did not require screening amounted to approximately 20 percent of the total amount of data focused on during this project.

Also, during 2023, the project team aggregated and sent the remaining 80 percent of data to the Navy's Commander Undersea Surveillance for pre-archival security screen-



Workflow.

ing. This included 140 terabytes of uncompressed HARP recordings, comprising approximately 129 individual deployment datasets and a set of 23 ARP recordings reprocessed for security screening.

Data sent for security screening were returned in the second half of 2024. In addition, a new batch processing tool, Passive Acoustic Collection Engine (PACE), was designed and implemented by NCEI for use in packaging multi-deployment passive acoustic submissions.

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

In 2025, the team used the PACE tool to process and package all remaining data for submittal to NCEI for archiving. The data are now available on the NCEI website.

2. **SoundCoop Case Study Project**

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

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

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

Archiving these datasets protects past Navy investments in passive acoustic monitoring and preserves these time series and early recordings. Including the data in the NCEI archive enables the data to be used in aggregate to help to quantify long-term changes in marine soundscapes. The effort has also helped to evaluate and advance processes for large-scale open access passive acoustic data archiving and hosting at a national level. The Navy will continue working to ensure that all remaining data are organized, archived and made available to the public for future analysis.

About the Principal Investigator

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

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 at-sea compliance and permitting process and ultimately helps to ensure uninterrupted training and testing.

Projects in this area can include hearing studies, sound exposure studies 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 seven ongoing projects and two new start projects.

Ongoing Projects

- Project 32—Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals
- Project 64—3S4–Effect of Continuous Active Sonar and Longer Duration Sonar Exposures
- Project 67—Measuring Behavioral Responses of Goose-beaked Whales to Continuous Active Sonar in the Atlantic
- Project 69—Effect of Signal Duration on Perceived Loudness in Bottlenose Dolphins and California Sea Lions
- Project 70—Behavioral Observations of Marine Mammals around Impulsive Noise (BOOMIN)
- Project 71—Masking Parameters for Pinnipeds: The Effects of Noise Bandwidth and Level on Signal Detection
- Project 76—California Sea Lion Movements and Foraging Behavior in the Channel Islands and Behavioral Responses to Experimental Naval Sonar

New Start Projects

- Project 79—Investigation of Temporary Threshold Shifts in Sea Turtles to Support Navy Compliance Permits
- Project 81—Continuous Active Sonar–Responses via Ecologically-based Documentation of Perturbation (CAS-REP).


MC2 Derek Cole

Ongoing Projects

Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

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

NEED

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

PROJECT

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

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

Hawaiian monk seals.
G. Puig-Santana, permit 22677

Hawaiian monk seal.
Colleen Reichmuth, permit 19590

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

KE18 was successfully transported back to Hawai'i 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 Hawai'i's Waikīkī Aquarium to the University of California Santa Cruz's Long Marine Laboratory. Both seals involved in this project have been deemed non-releasable by the National Marine Fisheries Service (NMFS) and are housed in long-term human care for zoological display, public education and conservation research.

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

Steps to prepare for in-air measurements were initiated in 2022, including building a new in-air testing apparatus and training KP2 for the task outdoors.

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

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

The project has two created educational videos about the work with these seals—one for Waikīkī Aquarium describing KP2's research in Santa Cruz (https://youtu.be/kC-9Vt3VxD4) and another about KE18's work while at the Pinniped Lab at UC Santa Cruz (https://youtu.be/1NpU2_456r4).

During 2024, the research focus shifted to the development of a combined detection and classification algorithm for Hawaiian monk seal underwater vocalizations. The team used a YOLO (You Only Look Once) v4 detection network trained on the COCO (Common Objects in Context) dataset to find and classify monk seal vocalizations within generated spectrogram images of acoustic recordings. The algorithm was applied to over four years of underwater recordings obtained from KP2 and KE18 in quiet conditions, resulting in a rich dataset of approximately 50,000 calls. These data confirm the species-typical vocal repertoire as well as seasonal and physiological patterns in sound production. Next steps in 2025 included adapting and testing the detector/classifier for field applications with free-ranging Hawaiian monk seals.

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

After finishing planned audiometric testing in 2024, monk seal KP2 was successfully transported back to Waikīkī Aquarium in Honolulu, Hawai'i in 2025. A manuscript describing his hearing in air and water—confirming that Hawaiian monk seals have poor auditory sensitivity relative to northern species like harbor seals—was published in *Endangered Species Research* in early 2025. (See Publication sidebar.)

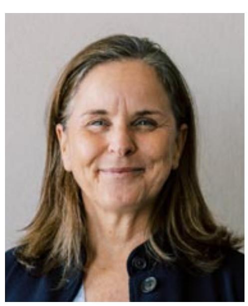
Research in 2025 focused on continued development and testing of the Hawaiian monk seal call detector. Building on initial efforts with laboratory datasets, the team re-trained the YOLO v4 detection network for field applications. The extensive field training set was created by combining high-quality, verified underwater calls (from the laboratory) with representative background noise samples (from field recordings) at a range of signal-to-noise ratios. The retrained algorithm was then successfully applied to detect the calls of free-ranging monk seals within field recordings from four focal sites in Hawaiian monk seal critical habitat.

The team created a standalone application that runs this field detector in Microsoft Windows and requires only raw acoustic input data. The output .csv file can be loaded directly into a standalone graphical user interface developed to support this work, which allows for efficient aural and visual review of machine-learning detections. These workflows can be immediately applied to efficiently screen large passive acoustic datasets for Hawaiian monk seals, with direct conservation implications for this endangered species.

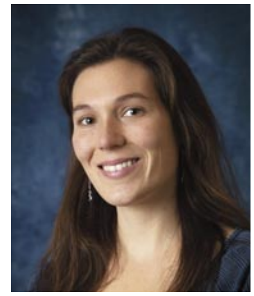
A comprehensive manuscript describing the detection and classification framework and its application to laboratory and field datasets will be submitted in early 2026. Next steps for the research program also include finalizing and submitting a manuscript describing typical Hawaiian monk seal terrestrial communication ranges, which should further improve environmental impact assessments.

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

About the Principal Investigators



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



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

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

Publication

Ruscher, B., Sills, J.M., Packard, N., Kendall, T.L., Williams, T.M. and Reichmuth, C. (2025). Psychoacoustic data confirm reduced hearing sensitivity in Hawaiian monk seals relative to Phocinae seals. *Endangered Species Research*, 56:19-26. DOI 10.3354/esr01377.

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

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

NEED

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

PROJECT

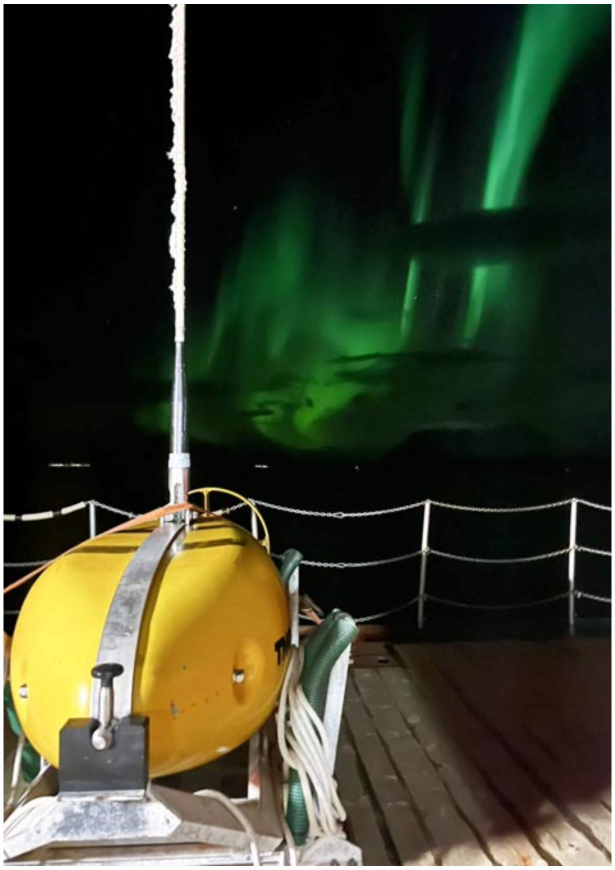
The 3S project has been conducting behavioral response studies on six different cetacean species in North Atlantic waters since 2006.

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

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

The project is supported in partnership with the LMR program and Canadian, French, Norwegian

Killer whale and HU *Sverdrup II*.
Kalliopi Gkikopoulou



Socrates (left) and HU *Sverdrup II* (right) with Aurora Borealis.
Frans-Peter Lam

and Dutch naval authorities, research organizations and the University of Iceland.

The project has completed three planned field efforts to collect data on animal responses to short- and long-duration CAS and PAS exposures using real-time GPS location data of multiple tagged subjects. Suction-cup attached mixed-DTAG+ and DTAG3+ units have included a DTAG3 core unit, VHF transmitter and a GPS-Argos unit built by Lotek. The source vessel has been equipped with a goniometer-receiving system for real time reception of Argos transmissions, and with the decoding system for GPS location data. For longer term tracking, satellite tags (SPLASH10-F-333B) were deployed early in the trials to collect information on animal movement over a longer timeframe (2–3 month expected tag duration).

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

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

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

The data analyses will include quantitative and qualitative analysis of data recorded by the animal-attached tag.

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

As of 2024, the project had collected more data than expected, but because the team had to use two different sonar frequency bands, and because the whales have a very conspicuous diurnal pattern with intense feeding behavior at night and resting behavior in daytime, more data were needed for conclusive results.

The 3S4 team completed it third and final field effort in October 2025. During this 18-day undertaking, the team deployed two SPLASH tags and 17 mixed-DTAG+s to killer whales and seven mixed-DTAG+s to humpback whales. As planned, they conducted four controlled exposure experiments (CEE): two with CAS and two with PAS. These CEEs included 10 animals (seven killer whales and three humpback whales). The CEEs were conducted during both daytime and nighttime, all using the Socrates low-frequency active sonar source transmitting 1.3–2.0 hyperbolic up-sweeps at max energy source level (ESL20s) of 214 dB re 1 µPa2sm2 for both CAS and PAS. While all CEEs were long duration five of the 10 tags detached before the start of the second approach. Thus, while data from all 10 tags are useful for CAS vs PAS comparison, only five will provide data to long-duration analyses. Overall, the team has now collected a rich dataset for analyzing the project's CAS vs PAS questions.

Two peer-reviewed publications and the 2025 Cruise report were released during 2025. (See Publications sidebar.)

Data collection is now completed and data analyses are on-going. Results will be published in peer-review literature in the coming years.

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

This project will provide valuable data to support new assessments.

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

About the Principal Investigators

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

Co-principal investigators are Petter Kvadsheim (FFI (Norwegian Defence Research Establishment)) and Patrick Miller (University of St Andrews Sea Mammal Research Unit).

Co-investigators: Peter Tyack and Saana Isojunno (University of St Andrews Sea Mammal Research Unit), Charlotte Curé (CEREMA (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning) France), Paul Wensveen and Filipa Samara (University of Iceland), Sander von Benda-Beckmann (TNO).

Publications

Curé, C., Isojunno, S., Wensveen, P.J., Siemensma, M.L., von Benda-Beckmann, A.M., Kvadsheim, P.H., Burslem, A., Benti, B., Roland, R., Lam, F.P.A. and Miller, P.J.O. (2025). Severity scoring of sperm whale (*Physeter macrocephalus*) behavioral responses to an operational sonar source reveals importance of received level and source-receiver distance. *Aquatic Mammals Journal*, 51(5):8-27. DOI 10.1578/AM.51.5.2025.8.

Haas, C.E., Wensveen, P.J., Hooker, S. K. and Miller, P.J.O. (2025). Acoustic characteristics and context of buzzes and rasps produced by northern bottlenose whales (*Hyperoodon ampullatus*). *Bioacoustics*, 34(2):93-119. DOI 10.1080/09524622.2025.2451955.

Kvadsheim, P.H., Binder, C., Brouns, E., Burslem, A., Giovannini, G., Hayward, E., Kleivane, L., Lam, F-P.A., Miller, P.J.O., Roland, R., Siemensma, M.L., Sato, G., Selbmann, A., van der Stappen, C. and Wensveen, P.J. (2025). Effect of naval sonar exposure on killer whales and humpback whales—3S-2024 cruise report. FFI report 25/015.

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

Principal Investigators: Douglas Nowacek, Brandon Southall, Andy Read
Project Status: Ongoing, Project 67

NEED

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

PROJECT

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

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

The experimental protocols include a pre-exposure period during which baseline behavioral data are collected prior to the CEE, followed by continued monitoring throughout the exposure and post-exposure periods. Experiments will be coordinated with operational Navy surface vessels capable of transmitting CAS signals through well-established procedures developed with U.S. Fleet Forces Command. The project team will deploy a simulated CAS source as a secondary option if CAS-capable Navy vessels are unavailable. Protocols also include full control CEEs (no known CAS or other MFAS exposure) with focal tagged and followed animals where possible. All operational parameters, general operating areas and experimental methods are strategically matched to past MFAS CEEs to enable comparisons of any behavioral changes as a function of signal type between conventional lower duty-cycle signals and CAS signals.

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

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

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

The 2025 field season, a single continuous effort from June through September, focused on CAS CEEs. This was one of the project's most successful campaigns thus far, in terms of Navy operational coordination, tagging and field operations, and the fielding of a new, key piece of equipment developed by the Navy. Multiple CAS-capable vessels were scheduled for possible coordination, thanks to sustained coordination and planning between the field team and U.S. Fleet Forces Command (USFF). These efforts yielded among the largest number of tags deployed (n=14) on beaked whales in any Navy-supported field seasons. Tag attachment duration was excellent with nine tags exceeding 30-day duration including the project's longest-ever at over 200 days and counting. The number of tagged high priority beaked whales monitored in CEEs provided substantial

Goose-beaked whale off Cape Hatteras.
Andy Read, NMFS permit 22156 (Andy Read/Duke University)

data. The team conducted two CEEs in 2025 with 11 total *Ziphius* CAS-exposure events. This included extensive coordination with the USS *Donald Cook* (DDG-75) to conduct just the second-ever CEE operational CAS. The team also successfully obtained, tested, fielded and calibrated a new operational CAS-capable MFAS sound source that was developed through direct support from the LMR program. This enabled the team to conduct the first-ever CEE with a high-power experimental source simulating CAS signal for *Ziphius*. The team also completed a manuscript on *Ziphius* MFAS response focused on simulated PAS signals, with publication anticipated in early 2026.

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

The Atlantic-BRS is planning a full field campaign in 2026 with tag deployments anticipated in June, ahead of already scheduled CAS-capable Navy ship availability in July. The team expects additional tag deployment windows in July and August ahead of additional scheduled and adaptively coordinated ships in August and September. The experimental MFAS source simulating CAS signals will be available to serve as a contingency source in conditions where field teams are present with tagged whales and Navy ships are unavailable. The team will also submit an additional PAS MFAS paper with the operational vessel CEE results for dozens of *Ziphius*.

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

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

About the Principal Investigators

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

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

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

Principal Investigator: Alyssa Accomando
Project Status: Ongoing, Project 69

NEED

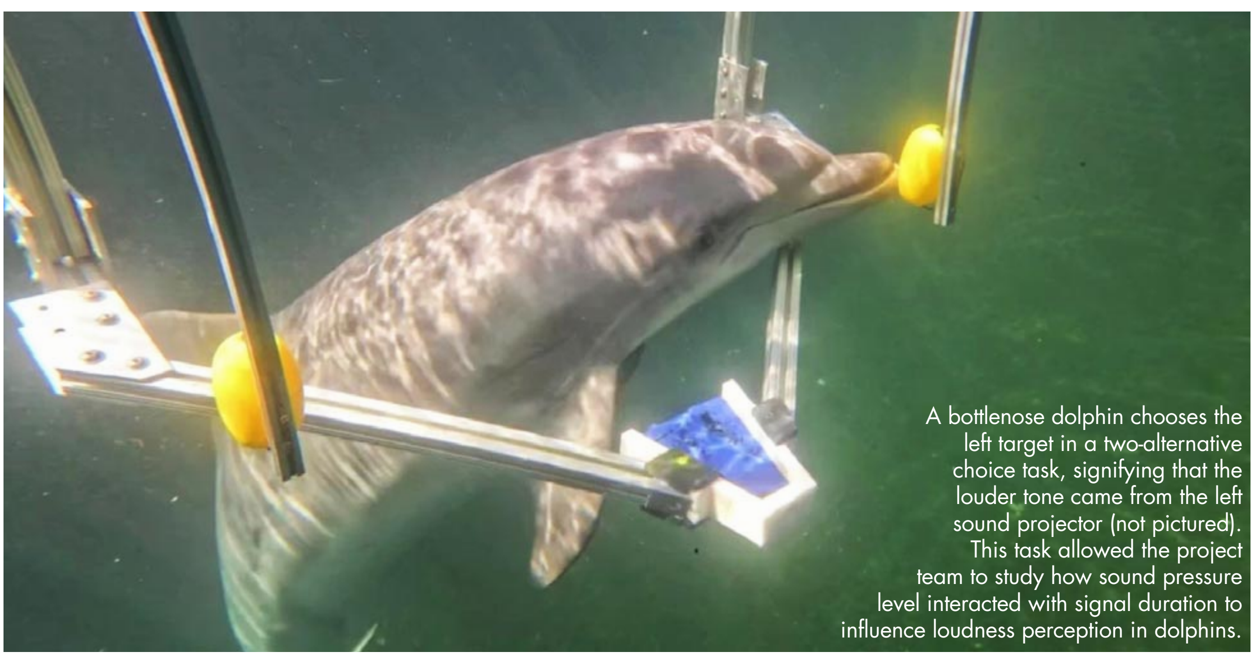
To understand the potential effects of sounds created by Navy training activities on marine mammals, the Navy needs information not only on physiological effects (i.e., temporary threshold shift, permanent threshold shift), but also how sounds can influence marine mammals' behavioral response. Both context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

PROJECT

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

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

1. **Threshold of signal duration audibility across the hearing range in dolphins**
   This task will use behavioral methods to test two trained bottlenose dolphins (*Tursiops truncatus*). The team will measure the threshold at which signals are audible for frequency-specific stimuli with durations between 25 and 1000 milliseconds (ms). The frequencies used will reflect a sample across the hearing range of dolphins (5, 10, 20, 40 and 80 kHz). Background masking noise will be played during testing to exceed the ambient sound in the testing location, which will elevate hearing thresholds to levels near those of Navy sources (>100 dB). Thresholds will be determined for



A bottlenose dolphin chooses the left target in a two-alternative choice task, signifying that the louder tone came from the left sound projector (not pictured). This task allowed the project team to study how sound pressure level interacted with signal duration to influence loudness perception in dolphins.

each combination of frequency and duration for each masking condition.

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

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

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

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

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

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

During 2024, the project team completed Task 1 data collection for dolphins and began training two dolphins for Task 2.

During 2025, two dolphins completed training and data collection for Task 2 (Perceived loudness as a function of signal duration in dolphins) and the project team started to analyze the results. Both dolphins provided data that were used to construct an equal-loudness contour as a function of signal duration, which is applicable to predicting the effects of Navy sources. Two manuscripts were submitted for chapters in *The Effects of Noise on Aquatic Life* proceedings, with publication expected in 2026.

In 2026, California sea lions will be trained to perform masked underwater hearing tests for different duration signals at multiple frequencies, and data collection will be completed.

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

About the Principal Investigator

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

Behavioral Observations of Marine Mammals around Impulsive Noise (BOOMIN)

Principal Investigators:
Erin Falcone, Stephanie Watwood
Project Status: Ongoing, Project 70

NEED

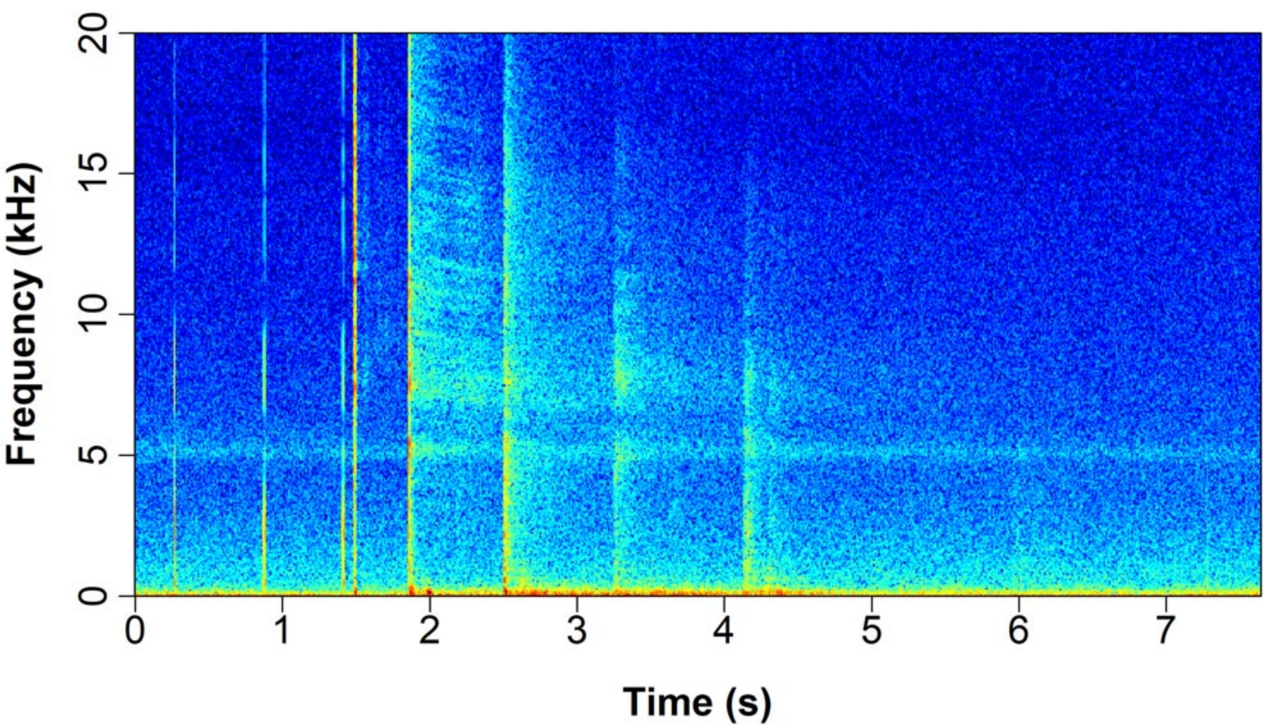
The U.S. Navy uses the Navy Standard Parabolic Equation (NPSE) (which utilizes CASS-GRAB) for modeling the sound field around Navy training and testing events, which can include detonations that generate explosive sound, to assess their impact on marine species. The effects of explosive sounds on marine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

PROJECT

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

The project includes three tasks:

1. **Before/During/After assessment of behavior during controlled detonations**
   The team will evaluate vocalization data from SOAR hydrophones and behavioral data from



Sample spectrogram from tag data collected during a live fire event.


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

the five SMRT tags deployed on animals prior to the July 2023 controlled explosive exposure experiment (LMR Project 35).

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

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

3. **Propagation modeling validation**

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

Through these tasks, the project will assess if

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

In mid-2024, the team began analyzing data from Project 35 controlled explosive experiments. Preliminary findings from the five SMRT tags analyzed under Task 1 included fine-scale changes in diving by a tagged beaked whale, which were coincident with the three highest SPL signals from the controlled detonations. Preliminary findings in Task 3 showed that modeled SPL and SEL values from the Navy Standard Parabolic Equation, which utilizes CASS-GRAB (NPSE/CASS-GRAB), were consistently higher than measured values collected under Project 35.

The team focused on Tasks 2 and 3 during 2025. As part of Task 2, the project team completed a comprehensive audit of 32 SMRT tags deployed on SOAR since 2019, logging all impulsive sounds detected during each deployment. The team completed a final report detailing the analysis conducted under Task 3.

Additionally, the team worked to determine the likely source of each impulsive sound detected on a tag. This work used information from the range operations schedule, range asset tracking records and acoustic localizations in the Marine Mammal Monitoring on Ranges (M3R) SOAR hydrophone archives. The resulting dataset, expected by mid-2026, will support efforts to analyze how whale behavior changes as a function of exposure to impulsive sounds while considering the source, location and received sound level of each exposure.

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

In 2026, the team will leverage a modeling framework that was designed to analyze the effects of military sonar exposure in these same deployments. The ability to account for other stimuli that may alter behavior, in this case assessing impulsive sounds as well as sonar, will considerably improve the understanding of the impacts of both these potentially disturbing sound sources that are common on SOAR.

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

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

About the Principal Investigators

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

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

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

Principal Investigators:
Colleen Reichmuth, Jillian Sills
Project Status: Ongoing, Project 71

NEED

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

PROJECT

This project is focused on providing quantitative auditory masking data for pinnipeds (odobenid, otariid and phocid carnivores) to improve knowledge of hearing and masking in these taxa and support at-sea compliance efforts within the Navy. The project expands upon another LMR-funded effort (LMR Project 61—Auditory Masking in Odobenid and Otariid Carnivores, completed in 2023) that characterized auditory masking from simultaneous noise in an odobenid carnivore, the Pacific walrus (*Odobenus rosmarus divergens*), and an otariid carnivore, the California sea lion (*Zalophus californianus*). With the addition of a phocid carnivore, this study includes one representative species from each of the three pinniped families. Results will describe auditory masking as a function of noise bandwidth and level, improving efforts to understand and predict the effects of noise on free-ranging marine mammals.

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

California sea lion at the University of California Santa Cruz's Long Marine Laboratory.
C. Reichmuth, NOAA/NMFS permit 25334

Spotted seal at Long Marine Laboratory.
C. Reichmuth, NOAA/NMFS permit 25334

at each test frequency. These critical bandwidths describe the specific frequency range of noise that contributes to masking a given sound.

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

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

During 2025, the planned masking work to evaluate the effects of noise bandwidth and level on signal detection was completed. Specifically, low-frequency critical bandwidths (100–200 Hz) were measured for one additional species, the spotted seal. These new data are consistent with prior measurements for the related bearded seal, confirming the superior frequency processing capabilities of seals at low frequencies relative to those of sea lions and walruses.

Data analysis and writing have been a primary focus. Two manuscripts were published (see Publications sidebar) during 2025. A review paper (book chapter) summarizing available knowledge and masking data was prepared for publication. Two manuscripts highlighting empirical data—one reporting direct critical bandwidth measurements across pinniped species and one describing masking onset and growth in sea lions—are being prepared for submission in 2026.

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

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

About the Principal Investigators

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

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

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

Publications

Reichmuth, C., Sills, J.M., Mulsow, J., Holt, M.M., and Southall, B.L. (2025). Temporary threshold shifts from mid-frequency airborne noise exposures in seals. *The Journal of the Acoustical Society of America*, 157(6):4685-4696. DOI 10.1121/10.0036849.

Sills, J.M., Ruscher, B., Packard, N., Jones, R.A., Southall, B.L. and Reichmuth, C. (2025). Low-frequency hearing and masking parameters in representative seals and sea lions. *The Journal of the Acoustical Society of America*, 158(2):1585-1599.
(Primarily supported by BOEM and JIP.)

California Sea Lion Movements and Foraging Behavior in the Channel Islands and Behavioral Responses to Experimental Naval Sonar

Principal Investigator: Daniel Costa
Project Status: Ongoing, Project 76

NEED

Existing data used in the Navy's Acoustic Effects Model (NAEMO) predict that the Navy has a large number of behavioral impacts on pinniped species from acoustic sources used during training and testing activities. However, the existing data were collected on cetacean species (whales and dolphins). The Navy needs behavioral response data from free ranging pinniped species to improve understanding of how sonar exposure may be affecting their behavior. Such behavioral response data will support compliance analysis modeling and enable Navy readiness.

PROJECT

This project is investigating if Navy sonar affects the at-sea behavior of California sea lions and working to quantify the potential population effect on this species. The effort will demonstrate the feasibility of successfully locating, tagging, tracking and measuring detailed aspects of behavior during controlled sonar exposures. It will provide data for both behavioral response analyses and Population Consequences of Disturbance (PCoD) modeling.

The project will monitor the fine-scale movement of individual sea lions using electronic tags and an array of drifting acoustic recorders to characterize source received level characteristics. Combined, these methods will allow the research team to monitor the response of focal individuals in controlled exposure experiments (CEEs). A mid-frequency active sonar (MFAS) source will be presented systematically (with other CEEs including known no-sonar controls), and the behavioral and acoustic response of focal individuals will be monitored in pre-exposure, exposure and post-exposure phases. Finally, the results of the fieldwork will be used to identify appropriate parameters for an updated, spatially explicit PCoD model. The primary objectives of this project include

1. Apply previously developed and executed methods to track sea lion movement to better characterize baseline (undisturbed behavior)

Tagged California sea lion on San Nicolas Island.
Dan Costa, NMFS permit 28912

California sea lions. *Dan Costa, NMFS permit 28912*

2. Obtain direct measurements of behavior from individual sea lions and assess their response (if any) to experimentally controlled, mid-frequency active sonar sources

3. Update the published PCoD model developed by the project team to include spatially explicit behavioral decisions to assess whether the sea lions observed behavioral response could negatively affect their population.

The team will deploy behavior tags and acoustic data loggers on lactating sea lions off southern California, on San Nicolas Island, home to one of the largest breeding aggregations of California sea lions. The lactating females are known to return to their pups after foraging. The tags will include Fastloc GPS, depth sensors, 3-axis accelerometers and acoustic data loggers (e.g., DTAG tag or similar). The team will collect baseline behavioral data from at least two foraging trips prior to starting acoustic exposures. This will also allow females to recover from capture and tag deployment.

The priority will be to examine the response of sea lions in locations where they are foraging. However, if time and resources permit, the sea lions' responses to sound exposure during transit will also be examined. These are the periods during which response to sonar is likely to have the greatest energetic effect. In addition to tag deployments, the team will collect blood, blubber and fecal samples from sea lions upon initial capture and recovery of any recaptured animals to evaluate physiological responses.

The project made significant progress during the 2025 pilot year to finalize experimental field operations and develop an analytical framework. As a pilot year, the primary goal of 2025 was to verify the experimental design, field test the tags and tracking methods, and conduct mock CEEs in realistic field scenarios. Multiple tag deployments were conducted in the spring, late summer and fall of 2025 at both San Nicolas Island and Año Nuevo Island in California to refine tag selection for at-sea tracking of adult female sea lions. Three different tags were identified as potential candidates: 1) Lotek tags that have been previously used for similar BRS work in other LMR funded projects, 2) cellular tracking Iridium network tags and 3) Wildlife Computers tags. Combinations of these different tag types were deployed on a total of 16 adult female California sea lions. Additionally, four of these females were instrumented with DTAGS and Wildlife computer's remote release devices. Of these four DTAGS, two were successfully recovered. The data were offloaded and are currently being processed and analyzed.

Additionally, at-sea live tracking was conducted aboard the *Valkyrie* in the fall of 2025. A team member from Project 57 (page 20) participated in the testing and demonstration of live tracking methods. During this time, the team successfully located and tracked previously tagged sea lions at sea around the northern Channel Islands. During these tracking events, the team conducted three mock control exposures, which helped to validate tracking protocols and provided critical procedural testing for future controlled exposure experiments.

These estimates of potential impacts are required to obtain at-sea compliance permits that enable the Navy to train and test.

Concurrently, progress on the California sea lion stochastic dynamic programming (SDP) model continued. Throughout 2025, physiological parameters were reviewed and coded, prey datasets were evaluated and incorporated to estimate spatially explicit prey biomass, and the model's spatial structure was defined. Initial coding of the SDP fitness functions and backward iteration was completed, followed by ongoing efforts to improve computational efficiency and validate model outputs to ensure biological realism and suitability for fine-scale spatial analyses.

During 2026, the team is planning two field efforts, one in spring and one in summer. The spring effort will focus on testing newly developed systems, including improved tag flotation and recovery mechanisms, to increase the reliability of DTAG recovery. Summer field activities are expected to build on these refinements and will include full-scale CEEs using a newly developed sound source.

This project will provide direct measures of previously unmeasured exposures and behavioral response of California sea lions to naval operations and assess whether these responses may have the potential to affect the population. The results will be directly incorporated into the Navy acoustic criteria and thresholds, which are needed to estimate incidental takes. These estimates of potential impacts are required to obtain at-sea compliance permits that enable the Navy to train and test.

About the Principal Investigator

Daniel Costa is Distinguished Professor of Ecology and Evolutionary Biology at University of California Santa Cruz and former Director of the Institute of Marine Sciences. His research focuses on the ecology and physiology of marine mammals. Dr. Costa has over 40 years of experience working on California sea lions and Northern elephant seals. Dr. Costa developed many of the capture and sedation methods still widely used today and has had multiple NMFS permits for similar work on California sea lions.

Co-investigators and key team members: Rachel Holser, Caroline Casey, Ryan Jones and Kelly Keen (University of California Santa Cruz), Brandon Southall (Southall Environmental Associates).

New Start Projects

Investigation of Temporary Threshold Shifts in Sea Turtles to Support Navy Compliance Permits

Principal Investigators: Aran Mooney, Wendy Piniak, Craig Harms
Project Status: New Start, Project 79

NEED

The Navy needs data on potential impacts to marine species from Navy training and testing activities. Identifying and measuring the potential effects of sound from such activities supports Navy acoustic threshold criteria. Recent underwater hearing studies indicate that freshwater and sea turtles can detect low-frequency sounds, and freshwater turtles can incur noise-induced hearing threshold shifts. These results suggest concern for similar auditory impacts for sea turtles from U.S. Naval activities such as underwater explosions, pile driving and low-frequency active sonar. The lack of empirical data on acoustic impacts to sea turtles limits the ability to quantify or mitigate these effects.

PROJECT

This project is measuring underwater temporary auditory threshold shifts in two sea turtle species. The project team will evaluate and refine methods used to test sea turtle hearing and measure temporary threshold shift (TTS), or temporary hearing loss, in freshwater turtles. Building from these methods, the team will explore sound exposure levels (SELs) that potentially induce sea turtle TTS onset. If TTS is induced, the team will quantify TTS growth (i.e., rate of increase relative to sound exposure level) and corresponding recovery rates. The work will seek to quantify TTS onset, growth and recovery for initial broadband exposures, followed by more comprehensive broadband exposures and narrow-band sounds.

The project includes three main tasks:

1. **Develop a robust, reproducible and safe protocol for testing sea turtle TTS**
   This includes characterizing potential hearing test environments. The goal is to determine the enclosures that are best suited for hearing measurements and noise exposures. Methods to manage the turtles and minimize stress during testing (balancing physical stationing and sedation) will be refined.

2. **Experimentally examine initial TTS using broadband sound signals in juvenile loggerhead sea turtles (*Caretta caretta*) and green sea turtles (*Chelonia mydas*)**
   Assess and compare initial TTS onset levels, as well as growth and recovery rates for these

Juvenile green sea turtle.
Philippe Bourjon, Creative Commons

two species. Empirically determine the apparent range of sound pressure levels (SPL) and durations (i.e., SEL) for effective mapping of sea turtle TTS, to provide the foundation for additional TTS studies. Because green sea turtles have substantially lower hearing thresholds than loggerheads, TTS onset could vary between species. The threshold difference could be as much as 20dB in regions of greatest sensitivity. This could result in varying noise response behaviors between the species.

3. **Address and compare, for both species, TTS onset levels, growth rates and recovery rates using 1/6th octave narrowband sound signals** Two fatiguing noise bands of interest will be addressed, as well as at least two hearing test frequencies for each noise band. Analyses will consider how TTS parameters may differ based on exposure frequency, and how those frequencies relate to the audiogram (i.e., regions of best hearing or more peripheral frequency band).

> The TTS data produced by this research will be directly useful for the Navy Acoustic Effects Criteria.

Results from this set of initial experiments could support later studies to address additional narrowband, as well as potential additional broadband and intermittent, noise exposures.

The TTS data produced by this research will be directly useful for Navy staff and researchers developing the next phase of the Navy Acoustic Effects Criteria, as well as Navy environmental compliance staff conducting analyses of the impacts of Naval sound-producing activities.

Currently no TTS data are available for sea turtles and the previously collected TTS data for freshwater turtles are being used for environmental analyses to estimate sea turtle TTS onset.

About the Principal Investigators

T. Aran Mooney leads the Sensory Ecology and Bioacoustics Lab within the Biology Department at the Woods Hole Oceanographic Institution. Dr. Mooney's research focuses on the hearing, bioacoustics and sensory abilities of marine animals. His lab has led the TTS work in freshwater turtles, developing protocols for noise exposure, sedation, calibrations and animal health and safety.

Wendy Piniak is a biologist in the NOAA Fisheries Office of Protected Resources. Dr. Piniak's research focus includes sea turtle acoustic ecology, and she has measured underwater and aerial hearing in diamondback terrapins and five species of sea turtle. She has extensive experience in turtle AEP techniques and examining sea turtle behavioral responses to sound.

Craig Harms is Professor of Aquatic, Wildlife and Zoo Animal Medicine at North Carolina State University and holds a specialty in zoological medicine. Dr. Harms also serves as veterinarian at the Karen Beasley Sea Turtle Rescue and Rehabilitation Center and backup veterinarian for the North Carolina Aquariums. Dr. Harms has pioneered several specialized methods in sea turtle medicine including underwater sea turtle anesthesia, which has been used to collect previous hearing measurements (AEPs) in green sea turtles and diamondback terrapins.

Continuous Active Sonar—Responses via Ecologically-based Documentation of Perturbation (CAS-REP)

Principal Investigators: Greg Schorr, Erin Falcone, Stacey DeRuiter
Project Status: New Start, Project 81

NEED

Results from previous behavioral response studies have indicated that both the type and the duration of Navy sonar signals may play a role in observed responses in marine mammals. As sonar technologies change, the Navy needs new information on the effects of new types of sonar on marine mammal hearing and behavior. Continuous active sonar (CAS) 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). With increased CAS use in training, the Navy needs more information to further understand the effects of CAS on marine mammals, particularly with additional marine mammal species.

PROJECT

This project is undertaking a thorough investigation into how anthropogenic sounds influence whale behavior, with a particular focus on beaked whales (*Ziphius cavirostris*) and the newer CAS systems that are increasingly used in anti-submarine warfare training within the Southern California Tactical Training Range. The growing sample of high-resolution data coming from Sound and Motion Recording and Transmitting (SMRT) tag deployments, which have captured a wide range of anthropogenic sounds that occur during training, and the long datasets from the Southern California range can provide more refined insights into animal responses.

The project team is leveraging past and ongoing SMRT tag deployments, as well as other available data with pulsed active sonar (PAS) and other signals, to analyze cetacean responses to CAS and other sound sources. Efforts focus on analysis, including support for additional data processing, model development and capacity building.

Primary analyses are evaluating two key questions:

1. Will exposure to CAS result in identifiable changes in diving and vocal behavior of individual tagged whales?
2. Will responses to CAS differ from responses to PAS in similar exposure contexts (e.g., maximum received level, cumulative sound exposure level, bout duration, distance to source)?

Initial work is focused on two main areas: 1) adapt and apply existing statistical methods and tools to handle and share big, high-resolution biologging datasets; and 2) develop and apply state-based models of animal behavior to quantify how beaked whales, fin whales and dolphins alter behavior in

Goose-beaked whale.
Erin A. Falcone, NMFS permit 16111

response to several types of underwater sounds associated with Naval training operations, using both tag and passive acoustic data sources.

The analyses will begin by using a Hierarchical Hidden Markov Model (HHMM) to integrate large samples of multi-scale data across individuals. Previous development of this approach has resulted in a robust, flexible statistical path forward for exposure data provided by the SMRT tags. This project will move the method toward completion and then document it and train other analysts in its use, thereby enabling this method to be applied to response work in other regions or with other species.

This project will leverage the Navy's prior investments in high-resolution data collection.

As the tools are refined and validated with beaked whales, the team will shift analyses to other species whose less-stereotyped behavior may present new analytical challenges. These may require additional data collection and model development to yield publishable results.

When the team has adequate samples of exposures to both PAS and CAS to address the main questions using the HHMM, they will move to publish those results. New tools and product outputs for the SMRT tags will be added to the existing GitHub site, providing the tools to other end users of the SMRT tags.

This project will leverage the Navy's prior investments in high-resolution data collection during both past and concurrent field work and provide more detailed analyses than previously completed. Results of this effort will support direct comparison between responses to CAS signals and to conventional, lower duty-cycle MFAS signals. The results will be applicable to other *Ziphius* populations subject to response studies and will provide data to inform the acoustic thresholds used in criteria development.

About the Principal Investigators

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

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

Stacy DeRuiter is an assistant professor at Calvin University where she teaches statistics and conducts applied statistics research. Her work includes statistical method development and applications, especially for dependent multivariate time-series. Specifically, Dr. DeRuiter uses biologging and acoustic data to understand how animals (mostly whales) change behavior in response to sound. She earned her Ph.D. in biological oceanography from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution joint program.

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 three ongoing projects and one new start project.

Ongoing Projects

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

New Start Project

- Project 75—Evaluating Population Consequences of Disturbance (PCoD) to Support Navy Compliance Permits

MC2 Timothy Dimal

Ongoing Projects

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

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

NEED

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 Biology (ONR MB) 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

Fin whale.
Simon Pierre Barrette, Creative Commons

Blue whale.
NOAA

tools and training materials to enable a wide range of stakeholders to estimate blue and fin whale density from OBS and CTBTO IMS data and other similar instrumentation.

This work is co-funded by LMR and ONR MB and builds on information compiled under previous ONR MB funding. The early tasks, funded by ONR MB, have included reviewing existing OBS and CTBTO IMS datasets from around the world, selecting a set of case study datasets containing blue whale and/or fin whale calls, comparing ranging methods, evaluating results and developing methods for density estimation. Varying conditions such as spatial configuration, hardware specifications and oceanographic settings of different arrays will dictate which signal processing methods, and therefore density estimation methods, can be applied to a given dataset.

The first part of the LMR-funded portion of the project has focused on signal processing of the OBS and CTBTO IMS case study datasets and implementing the density estimation methods developed under ONR funding. An additional task under this phase includes analyzing the case study datasets to explore various ecological and behavioral questions at a range of scales, from analyzing fine-scale tracks of calling whales to assessing large-scale spatial and temporal patterns of animal vocal activity. The project team will then focus on documenting the research software and case study datasets and developing training materials. The team will configure the software developed during the project so that the different code modules and data formats work together. This includes ensuring that the code for each ranging method produces outputs that are formatted for use with the density estimation algorithms (typically written in R, a free statistical software package).

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

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

Work in 2024 focused on preparing publications from the completed ONR MB-funded tasks and continuing LMR-funded tasks. The team estimated blue or fin whale densities in seven identified case studies across three different oceans and continued organizing the software documentation and training materials. Further, a Ph.D. student, who will work on a large-scale OBS deployment in the Atlantic Ocean to investigate fin whale density and distribution, started in 2024.

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

Work in 2025 concentrated on finalizing the project's case studies, which focus on estimating blue or fin whale densities at seven sites across three different oceans. The team also continued work to arrange documentation and training materials, including testing the materials with some new users. Results from the project were disseminated at five international conferences; two papers were published (see Publications sidebar) and two additional papers were submitted for publication.

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

About the Principal Investigators

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-principal investigators are Len Thomas, Tiago Marques and Peter Tyack (University of St Andrews, UK), Kevin Heaney (Applied Ocean Sciences, LLC, VA, USA), Luis Matias (University of Lisbon, Portugal), David K. Mellinger (Oregon State University, OR, USA) and Kerri D. Seger (re1 LLC, WA, USA).

Publications

Hilmo, R., Harris, D. and Wilcock, W.S.D. (2025). Applying distance sampling to estimate densities of fin whale calls recorded by ocean bottom seismometers in the Marianas region. *Endangered Species Research*, 58:159-174. DOI 10.3354/esr01439.

Harris, D.V., Mellinger, D.K., Heaney, K.D., Clarke, T., Miles, D. and Thomas, L. (2025). Estimating the detection probability of long-ranging baleen whale song using a single sensor: Towards density estimation. *The Journal of the Acoustical Society of America*, 158(6): 4582-4593. DOI 10.1121/10.0036892.

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

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

NEED

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

PROJECT

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

The Raven-X development team includes members from Naval Undersea Warfare Center (NUWC) and the Naval Information Warfare Center (NIWC) Pacific. The team plans to integrate existing acoustic detection, classification and location (DCL) algorithms into Raven-X. Both NUWC and NIWC have DCL algorithms that are customized for their needs and data formats. The team will focus on using Raven-X to read and analyze three types of Navy data formats: DAT, packet and Archive.

Over the course of this project, development has been organized around support for four main case studies.

1. **SoundCoop**
   During 2023, as part of an initial case study, the team successfully deployed and shared the Raven-X software package to labs both within and outside Navy, including NOAA's National Center for Environmental Information (NCEI). The team was able to utilize the tools within Raven-X to convert nearly two decades of community-provided ocean

Humpback whale.
David Csepp, NOAA

Fin whale.
Aqqa Rosing-Asvid, Creative Commons

recordings into calibrated sound measurements. This work has allowed the community, largely led by the SoundCoop team (see Project 66 in the LMR 2024 Annual Report, page 60), to develop recommended standards for ambient sound measurements. These recommended standards were directly integrated into the Raven-X software package to support future analysis.

2. **SanctSound Sonar Analysis**

   In 2024 the team set out to demonstrate the benefits of the Raven-X software package by incorporating an improved sonar detector that was developed under a now completed LMR project, Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar (see Project 34 in the LMR 2022 Annual Report, page 37). The Raven-X team then enhanced the detector by developing an advanced software package that uses intelligent machine learning methods to identify active sonar in large collections of acoustic recordings. By using the Raven-X software package, and Cornell's distributed computers, the team was able to successfully scan for sonar within seven years of acoustic recordings from the joint Navy and NOAA project, SanctSound. The analysis was completed in 2025 and incorporated into the Navy's Sanctuary Resource Statements as part of the Navy's environmental compliance process. A technical report detailing the methods and results of this work is expected in 2026.

3. **Fin Whale Cue Rate Study at PMRF and SOAR**

   Beginning in 2023 the team has supported a multi-year study funded by ONR. The team demonstrated the ability to integrate NUWC and NIWC algorithm technologies into Raven-X to obtain high-resolution tracking locations for low-frequency baleen whales. In 2024, the team worked on using Raven-X to process full bandwidth data (NIWC DAT format) collected over seven years from the Pacific Missile Range Facility (PMRF) hydrophone array to obtain fin whale calling data. The team produced high-resolution locations that were used to study song characteristics and animal movements at PMRF, results of which are published in an ONR/PACFLEET funded peer-reviewed manuscript (see Publications sidebar).

In 2025 the project processed a series of large datasets of full bandwidth data (NUWC packet recorder format) recorded from the Southern California Training Range. New and existing machine learning methods in Raven-X were used to classify several call types from baleen whales across three years of archival recordings, from 2017 to 2019, producing an estimate of animal presence/absence. Results will be published in a peer-reviewed manuscript in 2026.

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

4. **Locating Objects in Large Data Sets Using Archive Format from SOAR**

   During 2026 the project team plans to repeat high-resolution object location using audio recordings at PMRF and SOAR that use a special Navy data format known as Archive. A significant effort will be invested to utilize the Archive data, which reside in a compressed state and have the advantage of offering near continuous recordings as early as 2008 to present. The goal is to extend the same high-resolution methods used at PMRF and SOAR to provide continuous locations of acoustic objects such as fin whales, explosions and Navy sonar. The team will focus on compiling results into a comprehensive study that can inform other important research, such as animal movements and population estimates and how they coincide with Navy exercises. This work will culminate years of effort by NUWC and NIWC, delivering direct benefits to the Navy's mission.

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

About the Principal Investigator

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

Publication

Helble, T.A, Guazzo, R.A., Dugan, P.J., Alongi, G.C., Martin, C.R., Martin, S.W. and Henderson, E.E. (2025). Twelve years of fin whale song evolution in the central North Pacific. *Frontiers in Marine Science*, (12):1642598. DOI 10.3389/fmars.2025.1642598. (LMR supported the tool development.)

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

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

NEED

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

PROJECT

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

The project team started the project by investigating and refining approaches for call identification in low-frequency baleen whale species and mid-frequency toothed whales. Using results from that effort, the team is working to demonstrate and validate call identification techniques.

Analytical methods for baleen whale call identification being investigated include:

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

Methods for the mid-frequency species include:

- **Received level and angle-of-arrival information**
  Researchers will incorporate improved Time Difference of Arrival algorithms into analysis tools for digital acoustic recording tags (DTAG) and use simulations and empirical data to assess how call frequency and bandwidth affect angle-of-arrival estimation.
- **Spectral distortion**
  The team will measure the ratio of fundamental to harmonic energy within calls from prior analyses of dolphin whistles for focal identification.

A humpback whale tagged with a DTAG4 in the Stellwagen Bank National Marine Sanctuary.
Marine Conservation Research International, NMFS permit 27272 (David Wiley)

- **Low-frequency vibrations associated with sound production**

  This will use high sample-rate accelerometers to try to pick up low-frequency vibrations associated with sound production, similar to the accelerometer vibration work for baleen whales.

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

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

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

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

In 2024, the team completed two successful field efforts—one in Sarasota, focusing on bottlenose dolphins—and another in the Stellwagen Bank National Marine Sanctuary, focused on humpback whales. The team completed a framework to understand the factors limiting accelerometer call detection in cetaceans. Analyses were completed to understand a range of these factors including accelerometer sampling rate and filters, system and ambient noise, and vibration coupling. Preliminary analyses were done to investigate how call properties affect vibration signals, and this will be expanded next year. The first analyses were also completed for bottlenose dolphin caller-ID identification.

In 2025, the team completed the final planned field effort at Stellwagen Bank National Marine Sanctuary to instrument small groups of humpback whales with DTAG4s. During this trip, the team was able to use small unmanned aerial systems for tag deployment on humpback whales, which improved deployment efficiency, facilitated tagging all animals in the same social group and resulted in more consistent tag placement.

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

The team has completed validation of call identification methods for both model species. For humpback whales, the higher accelerometer sample rates supported by DTAG4s were not sufficient to identify calls from the tagged animals. Estimating individual call rates in this species will therefore require other approaches, such as simultaneously tagging multiple animals within small social groups. For mid-frequency toothed whale calls, current methods using stereo acoustic recording tags perform substantially better, but with important limitations that need to be accounted for during processing and interpretation. These findings are important for shaping best practice guidance for tag-based call rate estimation and will also help inform future tag development priorities.

In 2026, the team will focus on compiling and disseminating results. This will include completing and submitting research papers, refining and releasing software and curated datasets, and organizing a hands-on training workshop at the Society for Marine Mammalogy 2026 conference.

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

About the Principal Investigators

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

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

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

New Start Project

Evaluating Population Consequences of Disturbance (PCoD) to Support Navy Compliance Permits

Principal Investigator: Lars Bejder
Project Status: New Start, Project 75

NEED

To understand how marine species respond to Navy testing and training activities and the effects on marine species populations, it is increasingly important to consider multiple anthropogenic stressors. The Navy's Office of Naval Research Marine Biology (ONR MB) program has moved this area of investigation forward through work on Population Consequences of Disturbance (PCoD) models and extending to Population Consequences of Multiple Stressors (PCoMS), which links exposure to multiple stressors and population level effects. The potential effects of multiple stressors on marine mammal populations could influence short- and long-term responses to Navy activities. The Navy needs additional validation data for PCoMS models to support its compliance efforts.

PROJECT

This project is developing a suite of PCoMS models to evaluate alternative disturbance scenarios and to forecast population consequences for humpback whales. This information will improve understanding of basin-wide humpback whale energetic demands, physiology and reproductive biology in response to oceanographic and anthropogenic stressors. Funding from both the ONR MB and LMR programs is enabling an ongoing project to expand data collection and forecast modeling to explore oceanographic and anthropogenic stressors on humpback whale health.

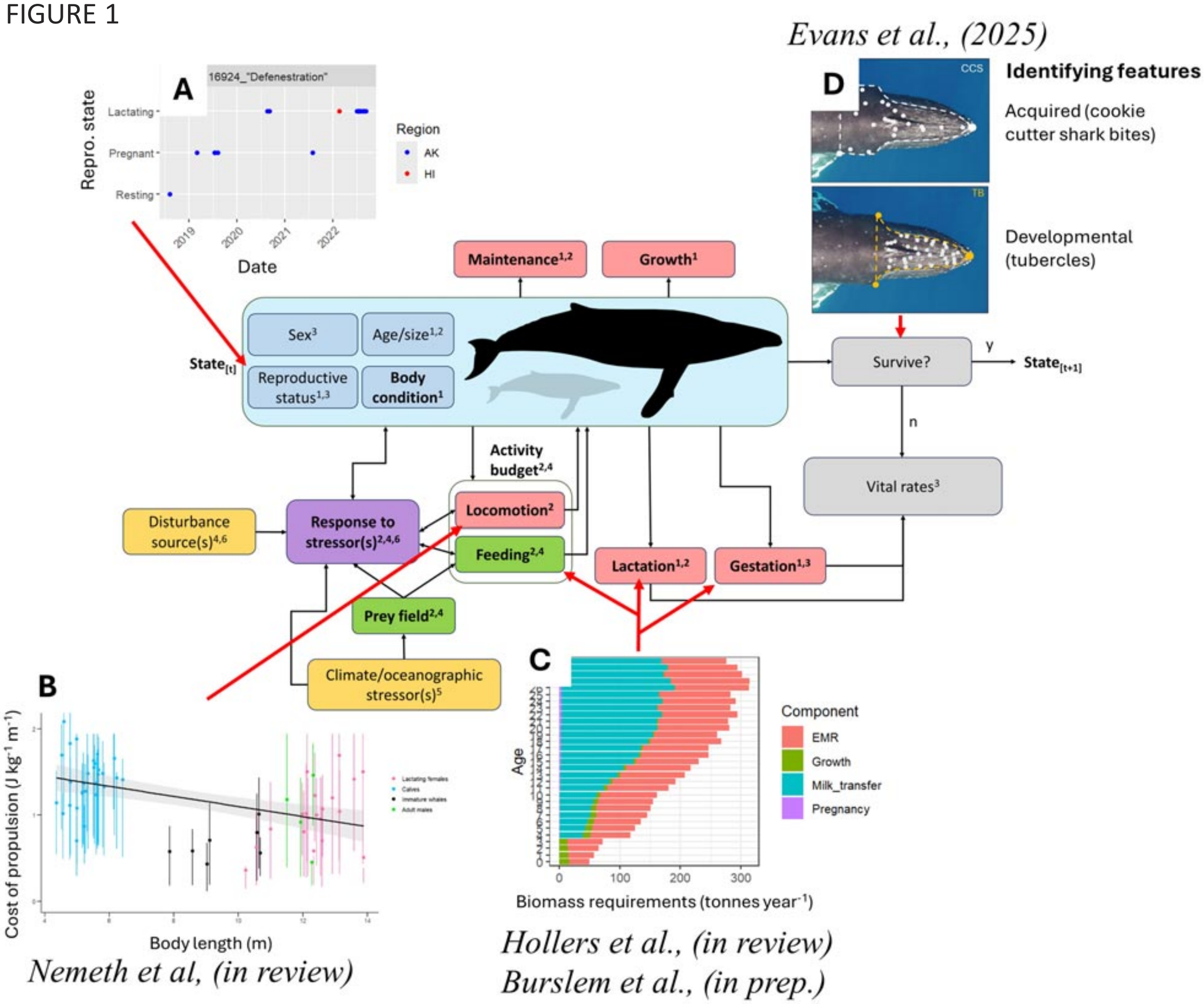
The Marine Mammal Research Program (MMRP) at the University of Hawai'i at Mānoa has an extensive dataset of humpback whale body condition measurements, collected in both Hawaiian breeding and Southeast Alaskan feeding grounds. The MMRP team will expand the dataset by collecting additional data in Hawai'i throughout the entire breeding season (January through April) over three years. This will maximize the probability of re-sampling individual whales throughout various points of the season. Re-samples provide invaluable

Tagging a humpback whale.
Marine Mammal Research Program, University of Hawai'i

information on individual rates of change relative to seasonal timing, demographic unit and reproductive status. The team will collect data using unoccupied aerial systems (UAS, aka drones), high-resolution tri-axial accelerometer video tags and photo identification. Data will include three-dimensional movement patterns, speeds, respiration rates and short-term behavioral responses to anthropogenic stimuli. The Hawaiian breeding ground tag data will provide detailed information on calf suckling rates and quantify behavioral budgets of tagged individuals. Photogrammetry data will be used to estimate body volume.

The team will couple the long-term, multi-year datasets on humpback whale body condition and volume acquisition rates with a suite of oceanographic data on sea surface temperature, salinity, upwelling indices, chlorophyll-a concentration and regional-scale climate data. After creating a comprehensive bioenergetic model for a large baleen whale, the team will then develop a suite of PCoMS models corresponding to alternative disturbance scenarios. This will include linking the response to stressors to vital rates and ultimately population consequences though their effects on body condition and other internal state variables. Efforts will include iterative model validation by comparing model predictions of population health with independent body condition and calving rate observations covering a significant proportion of the popula-

FIGURE 1



tion. Model validation and sensitivity analyses will be used throughout the project to identify any specific responses to anthropogenic stressors that require further investigation through experiment. When available, these analyses could include published state-dependent acoustic dose response curves.

In 2025 the team used available monitoring tag data to conduct multiple analyses needed for model inputs. The team worked to build key energetic baseline predictions that could be used to identify which stressor-response scenarios might be compared, including quantifying how propulsive energy costs scale with body size (Figure 1B). Another analysis compared breathing-rate and thrust-based methods for estimating behavioral-state-specific metabolic rates of mothers and calves in Hawai'i. The resulting manuscript was submitted for publication.

Results will improve understanding of marine mammal responses to multiple stressors and support Navy at-sea compliance efforts.

These new estimates of mother-calf metabolic rates were combined with other relevant findings in the published literature in a modeling analysis to predict the magnitude and age-sex structure of ocean-basin scale humpback whale prey biomass requirements on their feeding grounds in SE Alaska (Figure 1C). This analysis contributes to the overall modeling goals by developing important sub-models necessary to link prey availability and encounter rate to population trajectory. It also constitutes a key finding that will be submitted in early 2026 for publication.

The team developed and applied a drone-based photo-identification method to support future 'cradle to grave' tracking of individuals across life history states. Applying this to adult humpback whales is providing a foundation for extending individual tracking across typically hard-to-track life stages (Figure 1D).

In 2026, the team will conduct another data collection effort from January to March, which will include photogrammetry, biopsies and monitoring tag deployments. These efforts will further test deploying the tags from drones. Manuscript preparation will continue to share results.

This information will contribute greatly towards a better understanding of basin-wide humpback whale energetic demands, physiology and reproductive biology in response to oceanographic and anthropogenic stressors. Using this extensive dataset as a case study for a detailed PCoMS model will help the Navy determine whether it is feasible to assess population level impacts.

Results will improve understanding of marine mammal responses to multiple stressors and support Navy at-sea compliance efforts.

About the Principal Investigator

Lars Bejder is the director of the Marine Mammal Research Program (MMRP) at the University of Hawai'i at Mānoa. He has studied various aspects of cetacean biology, ecology and conservation, with a focus on developing quantitative methods to analyze behavioral ecology. He serves on the IUCN (International Union for Conservation of Nature) Cetacean Specialist Group and is a member of the expert panel on Marine Mammal Noise Exposure Criteria. Dr. Bejder earned his Ph.D. at Dalhousie University in Canada.

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 at-sea compliance and permitting processes.

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

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

The following section includes summaries of four ongoing projects. There were no new projects for this investment area in 2025.

Ongoing Projects

- Project 56—Integration and Field Evaluation of the Next Generation High-fidelity Sound and Movement Tags to Investigate Behavioral Response
- Project 59—Long-term Sparse Array Localization Feasibility Study using a SonarPoint System
- Project 68—Thermal Imaging for Vessel Strike Mitigation on Autonomous Vessels
- Project 72—UUV Technology to Enable Readiness of Navy Ranges


MC3 Hannah Donahue

Ongoing Projects

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

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

NEED

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

PROJECT

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

Work falls into three key tasks:

1. **Next-generation tag integration**

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

During 2023, 2024 and 2025 the project team continued the work on design and fabrication of the tags. Changes made to the fabrication process have simplified the tag subsystems and reduced the time needed to assemble a finished tag. The latest tags are shown in Figure 1. Additional design improvements have been made to the tag subsystems based on lab/field testing and feedback from other tag users:

- **Finishing**

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

- **Connector Assembly**

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

- **Release Assembly**

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

- **Releases**

  Tag releases were redesigned to improve the part manufacture process, reduce fabrication time and improve reliable performance.

Standalone tag electronics (DTAG4 Core Units) were also redesigned in 2025 (Figure 2). The redesign includes the updated release assembly and the improved hydrophone packaging.

The new design was considered stable as of the end of 2024, but the team has continued to monitor results from the lab/field testing and feedback from customers.

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

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

   - **Lab Testing**

     Lab testing has focused on suction cup performance and on tag acoustics.

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

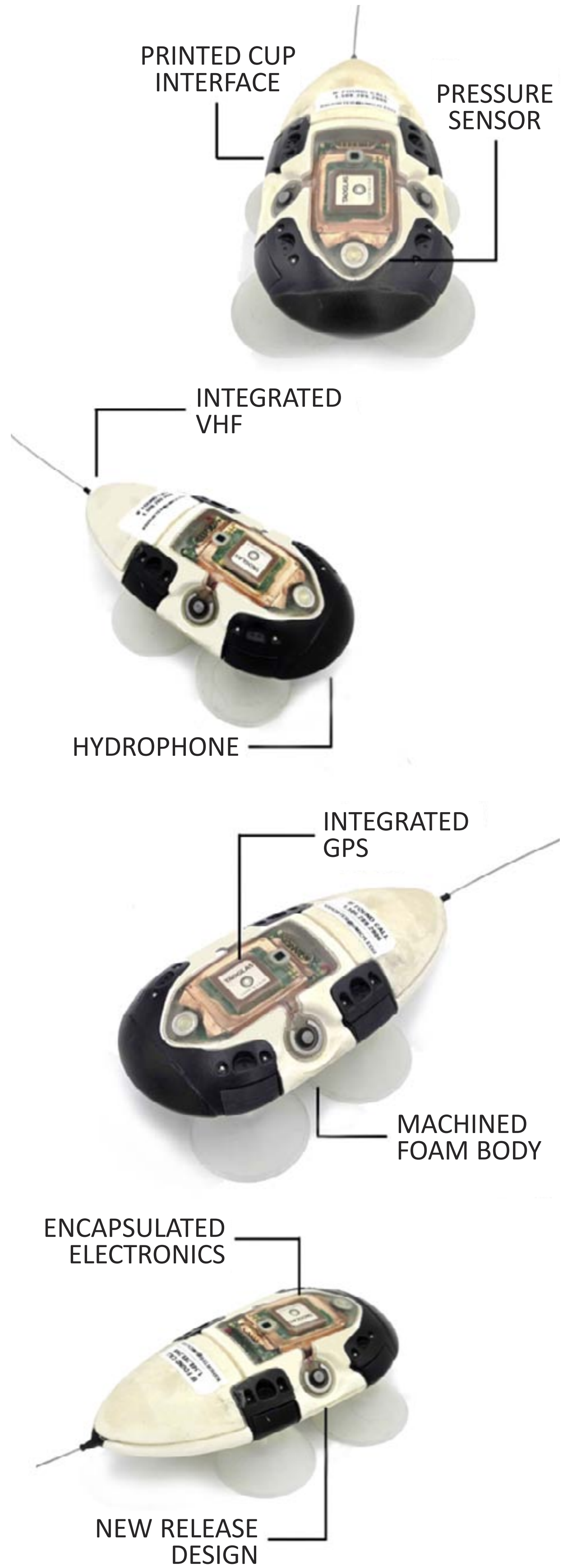


Figure 1: Images of the 2025 DTAG built around the DTAG4 electronics. Design improvements include new packaging for the hydrophone to improve robustness, a new release design, integrated VHF electronics and improved packaging for the integrated GPS.

these experiments were used to benchmark the hydrodynamics of the tag design, and to inform the requirements and specifications for the tag attachment system.

The team conducted acoustic testing at the Navy TRANSDEC (Transducer Evaluation Center) facility in Point Loma in both 2024 and 2025. The goals were similar in both years and included: 1) characterize the performance of the acoustic sensors on the tags, 2) measure any variability between tags, and 3) specify the directionality of the acoustic measurements in the vertical and horizontal planes (Figure 3). During 2024 testing, the team used two sound sources for the experimental measurements to characterize the low and medium frequency (20 Hz–20 kHz) response of the acoustic sensors. Before testing, a calibrated hydrophone (Type H52 hydrophone) was used to evaluate the source level for each tone at its specific testing location.

During the 2025 acoustic testing at the Navy TRANSDEC facility, eleven sensors were characterized, including four DTAG4s, four DTAG3s, a DTAG4 core unit, a soundtrap, and an external hydrophone. As in 2024, custom mounting structures were used to allow rotation around a vertical axis at a fixed distance from the source in both a vertical and horizontal configuration. This is used to characterize directional sensitivity of the acoustic measurements created by the body of the tag, particularly when the acoustic source is behind the tag.

The 2025 testing used three sources for the experimental measurements to characterize the low (20 Hz–1 kHz), medium frequency (1 kHz–20 kHz) and the high frequency (20 kHz–120 kHz) response of the acoustic sensors. A 'low' frequency source (Geo) was used to characterize the response from 20 Hz to 100 Hz and was located 2 meters away from the tag hydrophone. The 'medium' (1007–117) and 'high' frequency (ITC 1042 (Serial Number 919)) sources were used to characterize the response from 1000 Hz to 120 kHz and were placed 1 meter away from the hydrophone. Each tag and source were at a 6-meter depth for all tests. A calibrated hydrophone (Type H52 hydrophone) was used to evaluate the source level for each tone at its specific testing location prior to testing.

- **Field Testing**

  The tag field testing was conducted in 2023, 2024 and again in 2025.

During 2023, the team worked with collaborators at the Stellwagen Bank National Marine Sanctuary to complete a holistic

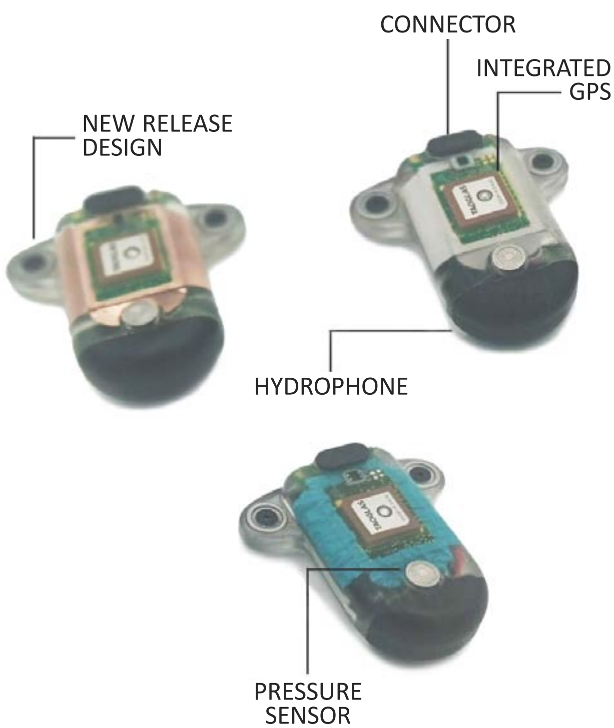


Figure 2: Images of the redesigned 2025 DTAG4 core units fabricated to support researchers conducting behavioral response studies using the LMR-supported mixed-DTAG. The redesign included improved features that were present in the 2025 version of the lease pool tags.

evaluation of the tagging system: deployment, attachment, release, recovery and measurement. All tags were successfully deployed and recovered during the field effort. Twenty tags were deployed during the field work, with attachment durations ranging from 1 to 20 hours. All tags were recovered using a combination of Argos/VHF tracking.

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

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

Stellwagen Bank National Marine Sanctuary—Collaborators deployed ten DTAG4s over two weeks in July 2024. Seven of the ten fabricated tags were deployed on 12 animals. Each of the seven tags was deployed an average of 1.5 times, and tags were set to release after 24 hours. A total of 173 hours of data were collected during the field work with tag deployments averaging approximately 12 hours. Three of the deployments lasted 24 hours. No tags were lost during the field effort. An onboard goniometer/antenna to receive Argos signals and a handheld Yagi antenna to receive VHF signals were again used, enhancing the team's ability to recover the tags.

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

During 2025 project collaborators at both the Hawaiian Islands Humpback Whale National Marine Sanctuary and the Stellwagen Bank National Marine Sanctuary tested DTAG4s,

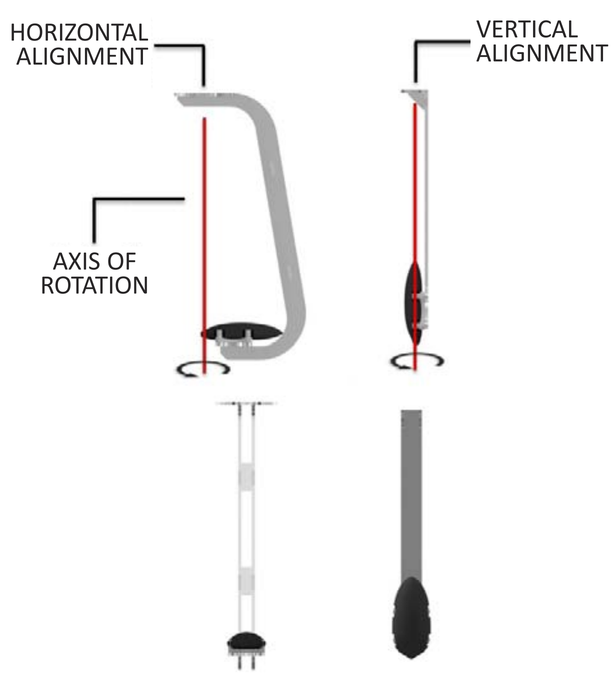


Figure 3: Schematic of tag orientation for TRANSDEC testing.

with integrated Lotek modules for localization and recovery. There were two approximately 10-day efforts in January 2025 in Hawai'i, and a two-week effort in June/July 2025 with the team at the Stellwagen Bank National Marine Sanctuary. In Hawai'i, tags were deployed on animals both in competitive pods as well as on solitary singing animals. As in 2024, the tags placed on animals in competitive pods tended to have short deployments. At Stellwagen Bank tags were deployed on groups of foraging animals. No tags were lost during the field effort. During recovery/tracking ARGOS signals were received by an on-board goniometer/antenna at a range of roughly 10 nm, while VHF signals had a range of roughly 5 nm with handheld Yagi antenna. Antennas were located at a similar height off the water during all field operations.

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

3. **Targeted support and training**

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

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

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

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

About the Principal Investigator

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

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

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

NEED

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. Office of Naval Research (ONR) Marine Biology program investments have identified multiple promising systems of low-cost, easily deployed arrays for monitoring data collection. The practical utility and benefits of these existing systems for collecting data for Navy marine species monitoring applications now needs to be demonstrated in a Navy-relevant context against other existing technologies and methods.

PROJECT

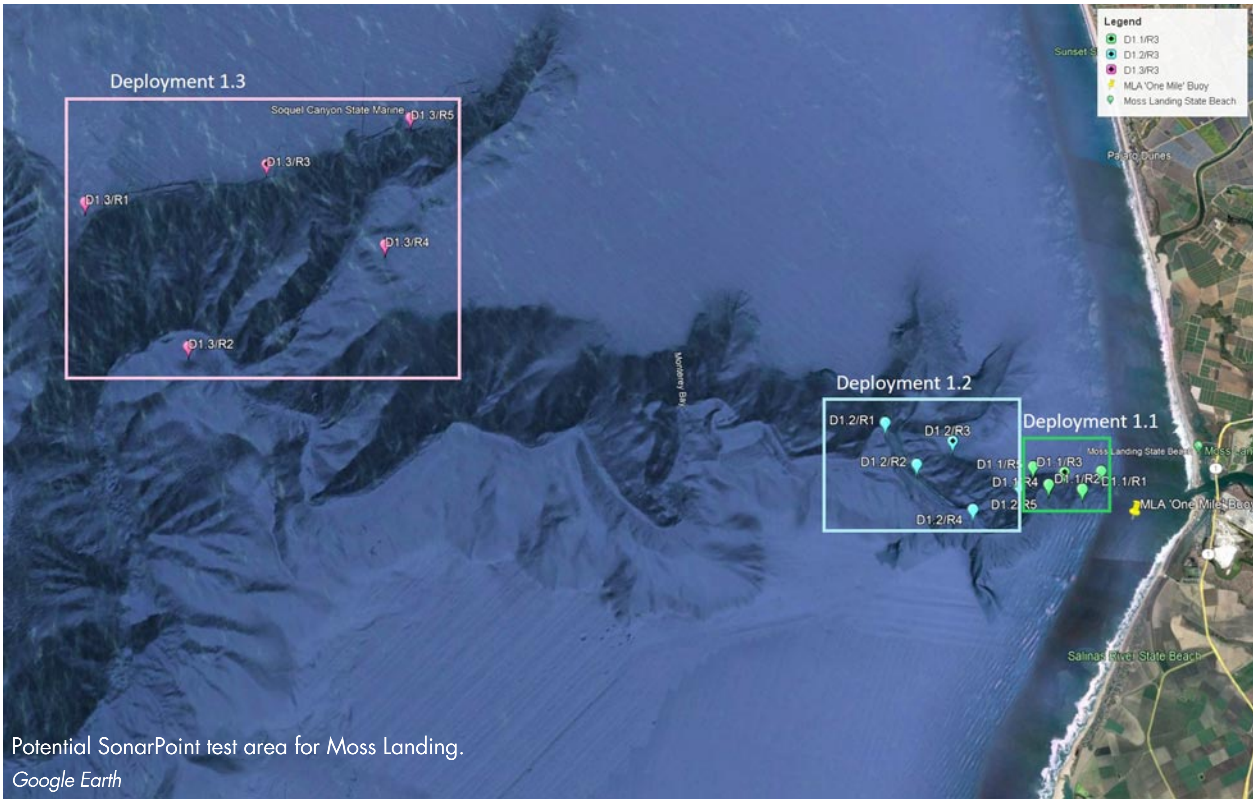
This project is assessing the functionality and durability of SonarPoint—a sparse array system developed by Desert Star Systems—for detecting and locating a variety of marine mammal species. The modular SonarPoint acoustic recorder uses a time synchronization pinger and multiple recorders configured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

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

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

The release problem was analyzed during 2024. It ultimately was traced to the effect of depth on the release:

SonarPoint mooring string.
Desert Star Systems



Potential SonarPoint test area for Moss Landing.
Google Earth

more energy is required to fuse the release wire at greater depth. The team worked to address technical issues and improve recovery success for future deployments. This included upgrading acoustic release hardware, adding a duplicate acoustic release and adding a satellite telemetry device to aid in recovery at the surface.

Five recorders, intended for short-term testing, were deployed at approximately 1000 meters in Fall 2025 (Deployment 1.3). Initially only two of the five recorders were recovered. The remaining three did not surface following system release because the plastic floats failed. With help from Monterey Bay Aquarium Research Institute (MBARI) using a remotely operated vehicle (ROV), one of the three missing recorders was recovered. Data recovered from the three recorders will be analyzed during 2026.

The Phase 2 and Phase 3 deployments are planned for 2026. The deployments are designed to demonstrate a longer-term operation of the SonarPoint system (months vs. weeks), expand the array to more than five recorders, increase the deployment depth (between 1000–2000 meters) and validate SonarPoint system localizations against another system (e.g., Naval range hydrophone arrays).

The data analysis component of this project combines both semi-automated processing to determine periods of vocalizing marine mammals and subsequent localization to candidate acoustic events. The team is using PAMGuard (version 2.02.15) to process and annotate the datasets for all potential marine mammal calls. An initial exploration of the PAMGuard Group 3D Localizer for this task demonstrated that the tool (originally optimized for use with echolocating porpoises) might be less suitable for localizing large whale calls from sparse arrays. In 2024, the team evaluated a MATLAB-based tool, Where's Whaledo, which had success localizing beaked whales using tetrahedral arrays. This semi-automated tool allows for a different approach to localization that includes a user-interactive method for identifying patterns in time-difference-of-arrival (TDOA) on hydrophone pairs within the array. The tool was modified to accommodate varied array configurations and required development of a detection approach for low-frequency baleen whale calls. Since the Deployment 1.2 dataset included adequate hydrophone spacing to assess humpback whale calls identified in the recordings, this species was used for initial evaluation and resulted in localizations. This analytical approach will be validated using data from Deployment 1.3 and will involve further testing and evaluation with multiple species.

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

In 2026, the team will evaluate an alternate localization method used for the Pacific Missile Range Facility (PMRF) site for data resulting from Deployment 1.3. An initial evaluation of humpback whale song suggested greater hydrophone spacing of 1–3 kilometers, at a minimum, is necessary for applying these methods. Adopting this methodology for baleen whales also provides the opportunity to obtain localizations with a well-vetted tool. For odontocetes, the project will also use the modified Where's Whaledo tool and continue to evaluate PAMGuard's Group 3D localizer for clicks. Deployment 2 will feature a nested array structure, including a shorter baseline (tighter) inner array and a longer baseline outer array. The inner array is expected to be more suitable for detecting clicks, which have a shorter detection range, and provide more precise TDOA measurements.

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

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

About the Principal Investigator

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

Key contributor: Elizabeth Ferguson (Ocean Science Analytics).

Thermal Imaging for Vessel Strike Mitigation on Autonomous Vessels

Principal Investigator: Daniel P. Zitterbart
Project Status: Ongoing, Project 68

NEED

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

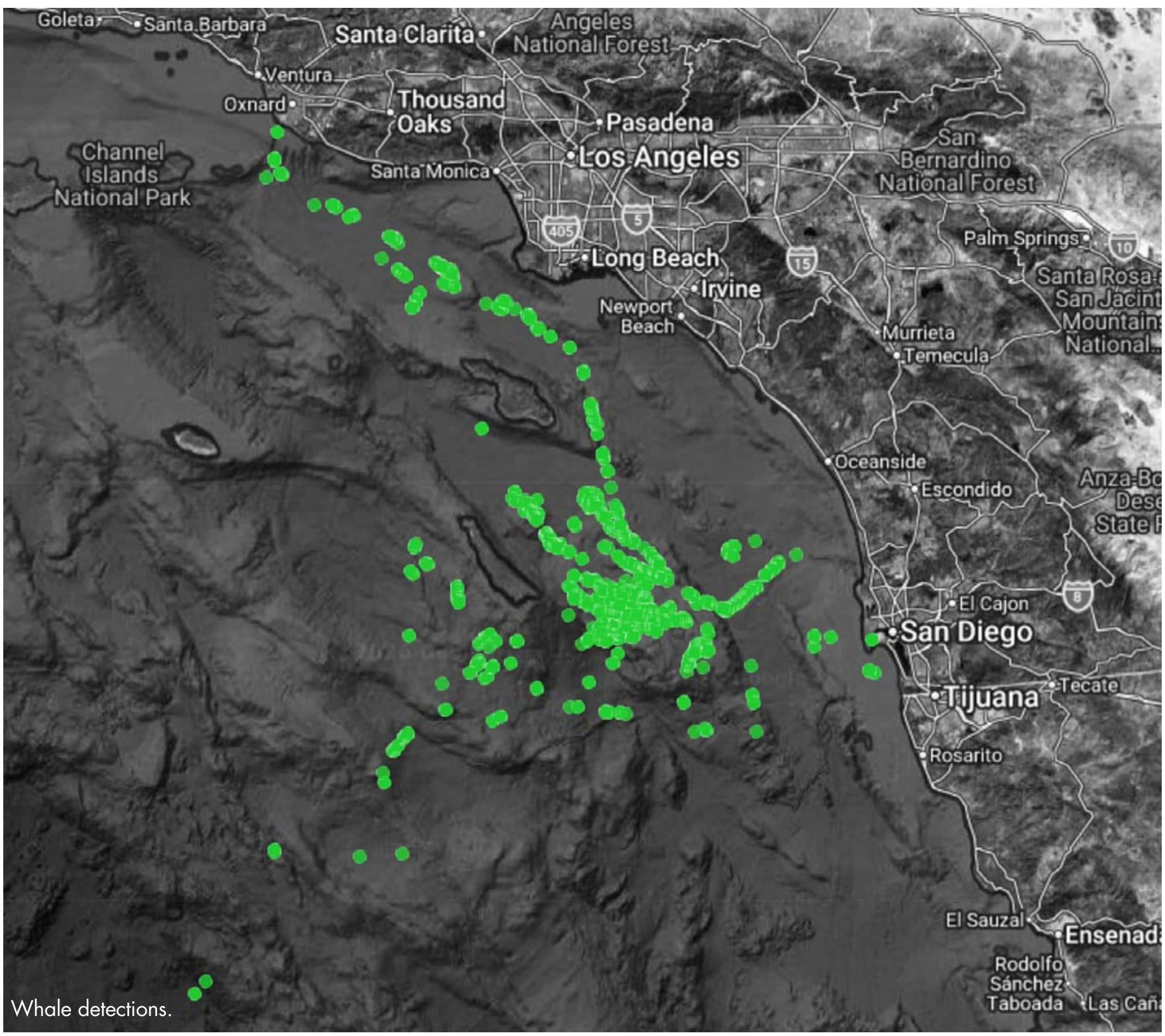
PROJECT

The project is focused on adapting and testing the WhaleSpotter thermal imaging-based whale

WhaleSpotter system.
Daniel P. Zitterbart

detection system to reduce the potential for vessel strike during navigation of unmanned Navy surface vessels. Following a phased approach, the project team is working through the following Navy needs: define mission-specific performance requirements, assess data collection and performance, modify detection and classification algorithms, reduce false alert rates, remove the existing real-time detection verification, evaluate Navy Information Technology (IT) system compatibility, incorporate detections into the command and control of unmanned surface vessels, and program the decision tree of actions that are required when a detection occurs.

Initial efforts, in Phase one, provided a plan and design for the project to proceed through the outlined needs. During 2024 the team assessed the detection ranges needed to operate the technology on Navy unmanned surface vessels as well as the potential use of existing technology. The team evaluated the variety of thermal imaging systems being considered for future unmanned surface vessels. However, since a single system has not yet been selected, the team determined that these options could not provide a hardware basis for whale detection at this time. Furthermore, due to the high maneuverability of unmanned sur-



Whale detections.

face vessels, the detection ranges that can be reliably achieved with the existing WhaleSpotter system are sufficient.

In 2025, the project team advanced the WhaleSpotter thermal-imaging capability toward operational deployment on Navy unmanned surface vessels. They updated the WhaleSpotter units to support autonomous use and tested its offline functionality during a research cruise with the National Oceanic and Atmospheric Administration cruise in June.

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

In the second half of 2025, the focus shifted to field testing with the device installed on Navy unmanned surface vessels. This initial testing was set up in a passive mode, which collects detection data without real-time verification by a human and does not require an active network connection to the vessel. The data are stored on the system itself and analyzed after each operational period is complete. It is important to note that the vessel command and control system does not currently receive the detection reports because the two systems (detection and command and control) are not integrated. This function will be addressed in a future phase following further development.

Team members conducted multiple site visits to Port Hueneme and San Diego to prepare WhaleSpotter installations on autonomous Navy vessels. WhaleSpotter units were installed on *Mariner* and *Seahawk* and operated through the end of 2025. The *Mariner* unit ran reliably through two operational periods, logging 106 marine mammal encounters (each encounter may be made up of multiple individual detections) and 1,670 detections (each time a blow/body is seen on the IR camera) total. The *Seahawk* unit likewise operated without technical malfunction, logging 67 encounters and 1,783 detections total across two operational periods.

In 2026 the team plans to operate the installed WhaleSpotter units continuously to collect more relevant data from Navy unmanned surface vessels. The subsequent data analysis will lead to Phase II. In this phase the team will work to improve the detection algorithm to keep both the number of incorrectly identified whales (false alerts) and the number of missed whales (false negatives) at an absolute minimum.

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

About the Principal Investigator

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

UUV Technology to Enable Readiness of Navy Ranges

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

NEED

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

PROJECT

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

During Phase II (2022–2023), the team proceeded to develop and test its Directional Cetacean Acoustic Recorder (DICAR) that features low-frequency and high-frequency acoustic receiver arrays to monitor marine mammal species of interest. The recorder can archive the data, with the potential future capability of running detection and classification software to enable transmitting

Goose-beaked whale.

detection events in nearly real time. Initial testing of the DICAR system in controlled aquatic settings demonstrated that it could provide directionality in the target frequency bands when integrated with Seaglider. Based on these results, the LMR program decided to co-fund an expanded Phase II with the SBIR program.

A successful system could offer a cost-effective platform for extended surveying periods.

During the expanded Phase II (2024–2025), the team focused on integrating the acoustic recorder into the platform, achieving proper balancing and ballasting of the platform with all components integrated, completing two full engineering tests, and conducting one short field test. Test goals included demonstrating both platform and recording technology performance.

In 2024, the team conducted high-frequency (HF) testing in a controlled environment at University of New Hampshire. The goal was to characterize HF array directionality measurements from a wide range of bearings and inclinations. Results showed that that the system acquired good data on all channels, verifying system integration design. Subsequent low-frequency (LF) testing was conducted in Cayuga Lake, New York. This test replicated how the glider would fly under normal operation and measured the directional accuracy of the DICAR arrays. A full set of LF data, including positive and negative inclinations, was collected and DICAR integration and tracking capabilities were confirmed.

In 2025 the team conducted a full engineering shake-down deployment off the coast of Oregon. This effort worked to demonstrate integrating the COTS (commercial-off-the-shelf) embedded recorders, perform balancing and ballasting, and obtain data for performance evaluation. While low-frequency tones were successfully recorded and tracked, the high-frequency tones were not recorded. The speaker producing the sounds might not being strong enough at high frequencies. The successful deployment, piloting and recovery of the seaglider and DICAR payload system is promising.

A second Phase II will be funded in 2026 to focus on additional system development and demonstration in an ocean environment. The team will assess the system's endurance and power management, as well as ability of the recorders and algorithms to differentiate individual calling animals.

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

About the Principal Investigator

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

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

INVESTMENT AREA 4
STANDARDS AND METRICS

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

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

The following section includes one new project for 2025.

New Start Project

- Project 74—Navy Received Level Propagation Modeling Alignment Working Group

MC3 Gary Buckles

New Start Project

Navy Received Level Propagation Modeling Alignment Working Group

Principal Investigator: Elizabeth Henderson
Project Status: New Start, Project 74

NEED

The Navy uses behavioral response functions in environmental compliance analyses and take estimates. Traditionally the response data are only used in the models if they include a measured received level (e.g., an acoustic tag recording). For tags that do not include acoustic recording capabilities and for passive acoustic monitoring used to track marine mammals, received levels are often based on propagation modeling. Because multiple propagation modeling methods are used, the Navy needs more information on the various models and how outcomes could vary.

PROJECT

This project will convene a working group to examine existing propagation models and their underlying assumptions and methodologies. The group will include Navy and non-Navy research partners currently using propagation models in their analyses. Using common datasets in various types of propagation models (e.g., ray tracing, normal mode and parabolic equation models), the participants will adjust model parameters and compare outcomes to understand how each model works. The group will consider modeling paradigms when animal or source locations are uncertain and will propose a unified approach to be considered by all groups relying on propagation-modeled received levels to promote comparable values across projects and regions. This is not intended to require use of a single model but will work toward outcomes that can be compared and used reliably when combined in future risk function development.

The group will include multiple teams to address modeling, analysis and field work. The modeling team will run and iteratively test the different propagation models. The analysis team will help to process and compare the model results. The field team, to include those who collect and use data, will contribute tag data for testing and comparison, and to support the data analyses. Outside technical experts could also be involved as consultants on topics of propagation if needed.

Work will be organized into four primary tasks.

1. **Initial propagation model comparison and analysis**

   The project lead will work with each of the modeling team members to complete an initial basic propagation model comparison and analysis. Insights and lessons will be compiled into a report to be shared with the whole working group and used as the starting point for the full analysis.

2. **Detailed propagation model comparisons**

   The working group will then make initial decisions regarding which datasets and model parameters to use for modeling, how to deal with positional uncertainty and what other approaches to consider. The modeling team, supported by the analysis team as needed, will process the agreed upon test dataset(s) using the selected propagation models and parameters. This will be an iterative process in which multiple datasets are selected that capture the different environments, focal species and signals relative to each contributing project. Following each test round, the team will discuss input parameters and compare outputs.

   Once the preceding steps are completed, the full team will meet to compare and discuss the results.

3. **Discussion of reporting metrics**

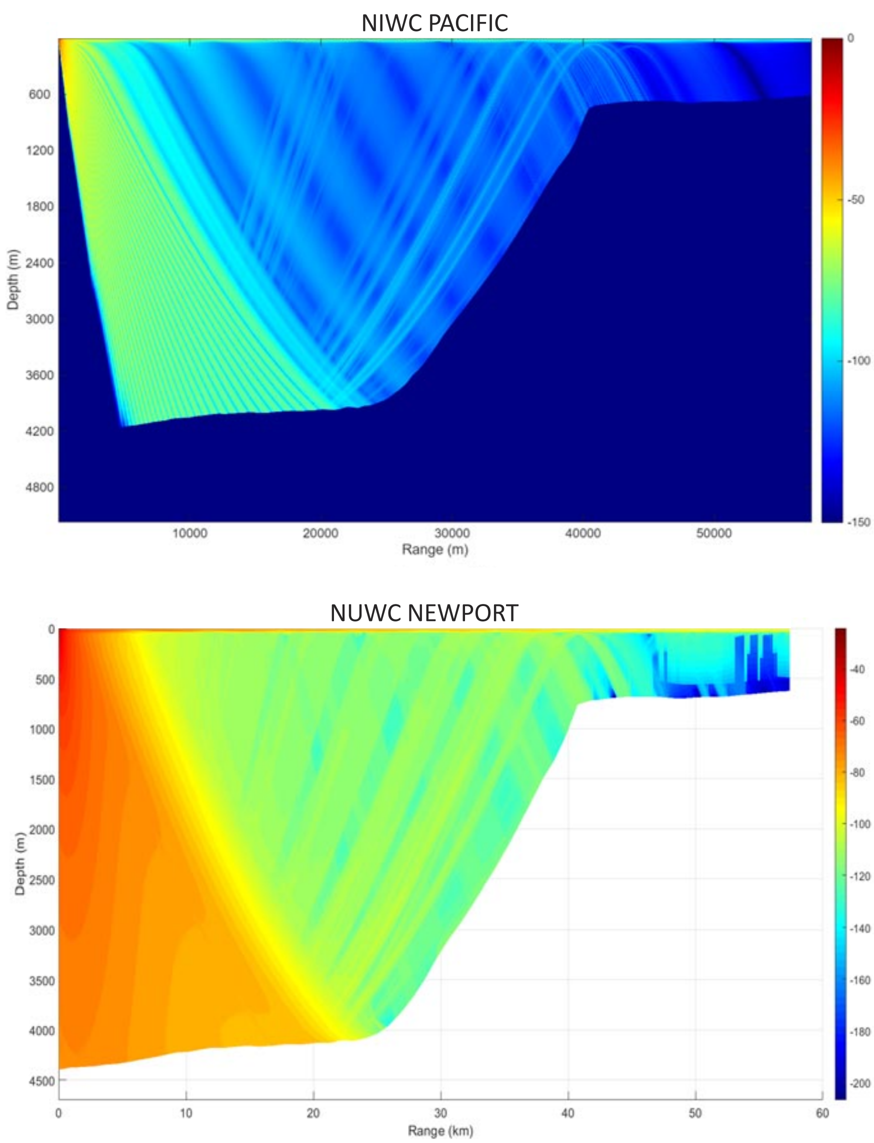
   The analysis team will discuss the different approaches currently used and will present the types of metrics reported and how they are reported. This will guide best practices for reporting the model outputs, with a goal of a unified approach on reporting metrics and variance that can be used in future behavioral response functions (or other Navy applications).

4. **Determination of aligned modeling approaches**

   All preceding pieces will be compiled, and the full working group will meet to discuss lessons learned on input parameters, modeling approaches and reporting methods. The goal will be to come to an agreement on how to move forward to achieve reasonably comparable results in the future when using different models.

The working group will prepare a final technical report that describes the results of the model comparison, the metrics selected for reporting and the final outcomes. This could be used as a guide for working group members as well as future modeling efforts to ensure continued alignment.

During 2025, four subgroups in the modeling team conducted a series of acoustic propagation modeling tests using each group's standard propagation modeling code and underlying variables, as well as with a set of standardized variables. These tests were conducted in three different regions over two seasons to capture a variety of bathymetric and environmental scenarios. The tests used identically placed sources, acoustic recorders and hypothetical animats at various depths in the water column. The data were taken from locations where opportunistic or controlled exposure studies have been conducted and actual mid-fre-

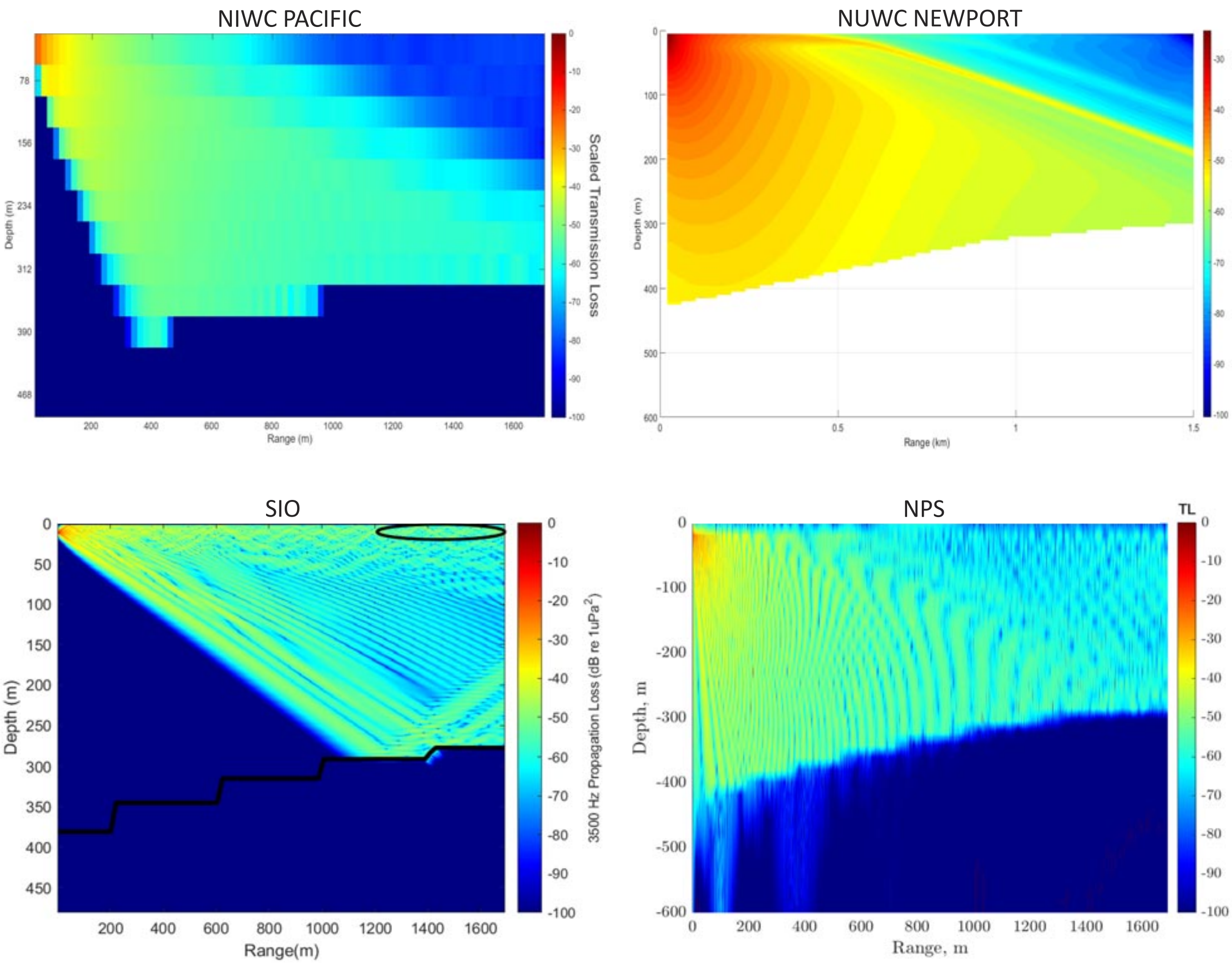


Comparison of transmission loss along a single radial at PMRF in August 2023 between the Peregrine propagation modeling package used by NIWC Pacific (top) and the propagation modeling package used by NUWC Newport (bottom).

quency active sonar (MFAS) from surface ships, helicopter-dips or simulated sources has been recorded. These data provided measured received levels against which the resulting modeled received levels could be compared. These regions include the PMRF range in Hawai'i, the SOAR range in southern California—as well as an additional off-range site in southern California for comparison—and an area off Cape Hatteras in the Atlantic.

The working group met multiple times during 2025 to: 1) discuss how the analyses should be conducted and what data to use, 2) compare initial results and discuss issues or concerns that had arisen in the initial test phase, and 3) compare a second set of results with better underlying comparable shared variables and discuss a few final parameters to test and run. In addition, the project's principal investigator conducted on-site visits throughout the year with all the teams for in-person discussions about each model being used and the associated underlying infrastructure and assumptions. These visits and discussions were invaluable in making modeling decisions and identifying ways forward for each team and the full working group.

While in some instances the resulting modeled received levels were close to measured levels, or modeled levels were similar across teams, in other cases modeled received levels differed



Comparison of a single transmission loss radial between NIWC Pacific (top left), NUWC Newport (top right), Scripps Institution of Oceanography (bottom left) and Naval Postgraduate School (bottom right).

widely across teams, even when major variables (bathymetric models, sound speed profiles, sediment type) were held constant. This revealed that while these major variables could be manipulated and controlled, there were multiple underlying variables and assumptions that differed between models that could not be modified. These nuanced differences may have led to the large variability in modeling results. The internal propagation models also handled specific scenarios (such as steep angles or close ranges between the source and bottom-mounted receivers) differently. These differences will continue to be explored in Year Two, as will additional data sources, reporting metrics and other modeling questions.

This project will enable more consistent use of received level data resulting from ongoing behavioral response studies.

In 2026, the remaining working group members will join the project, including the research scientists conducting the field work and the statisticians modeling the resulting data post-processing. While the working group will continue to explore what might be causing the differences in modeling results with inputs from the broader team, the focus will shift from the underlying differences in the models to what and how the resulting received level data are dealt with once they are processed, including what metrics should be calculated and reported. The group will also focus on how the different modeling teams can best work to align their results even when differences are likely to continue to occur. Some future modifications could include slight changes in the way each team conducts their modeling (e.g., what underlying variables can be used moving forward to be better aligned), or options for more consistently summarizing received levels over a similar area in the water column versus reporting a single value. These are examples of discussions and decisions for teams and the larger working group to address in the second year of the project. The group will work to complete a manuscript for publication during 2026.

This project will enable more consistent use of received level data resulting from ongoing behavioral response studies that utilize passive acoustics or non-acoustic tags (e.g., satellite tags). It will also provide practitioners who analyze tag data clear guidance on the different propagation models and when each may be more appropriate for use. This has the potential to result in additional behavioral response data being incorporated into future Navy behavioral response functions and the permitting processes.

About the Principal Investigator

Elizabeth Henderson is a bioacoustics scientist at the Naval Information Warfare Systems Center (NIWC) Pacific and leads NIWC's Whale Acoustic Reconnaissance Project Lab. She has extensive experience analyzing marine mammal acoustic behavior and noise impacts for environmental compliance and developed the Navy's Behavioral Risk Functions in Phase III and Phase IV of the Navy's environmental compliance assessment. Her expertise includes cetacean behavioral ecology, bioacoustics and behavioral responses to anthropogenic activities. Dr. Henderson earned her Biological Oceanography and Bioacoustics Ph.D. at the University of California

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 at-sea compliance and permitting processes, or topics that do not squarely fall within the preceding categories. Two new projects were started in 2025.

New Start Projects

- Project 78—Advancing the Navy Acoustic Effects Model (NAEMO)
- Project 80—Measurement and Quantification of Acoustic Energy Radiated into the Ocean from a Near Surface Airborne Explosion

Michael Wilson

New Start Projects

Advancing the Navy Acoustic Effects Model (NAEMO)

Principal Investigators:
Samantha Simmons, Magda Chudzińska
Project Status: New Start, Project 78

NEED

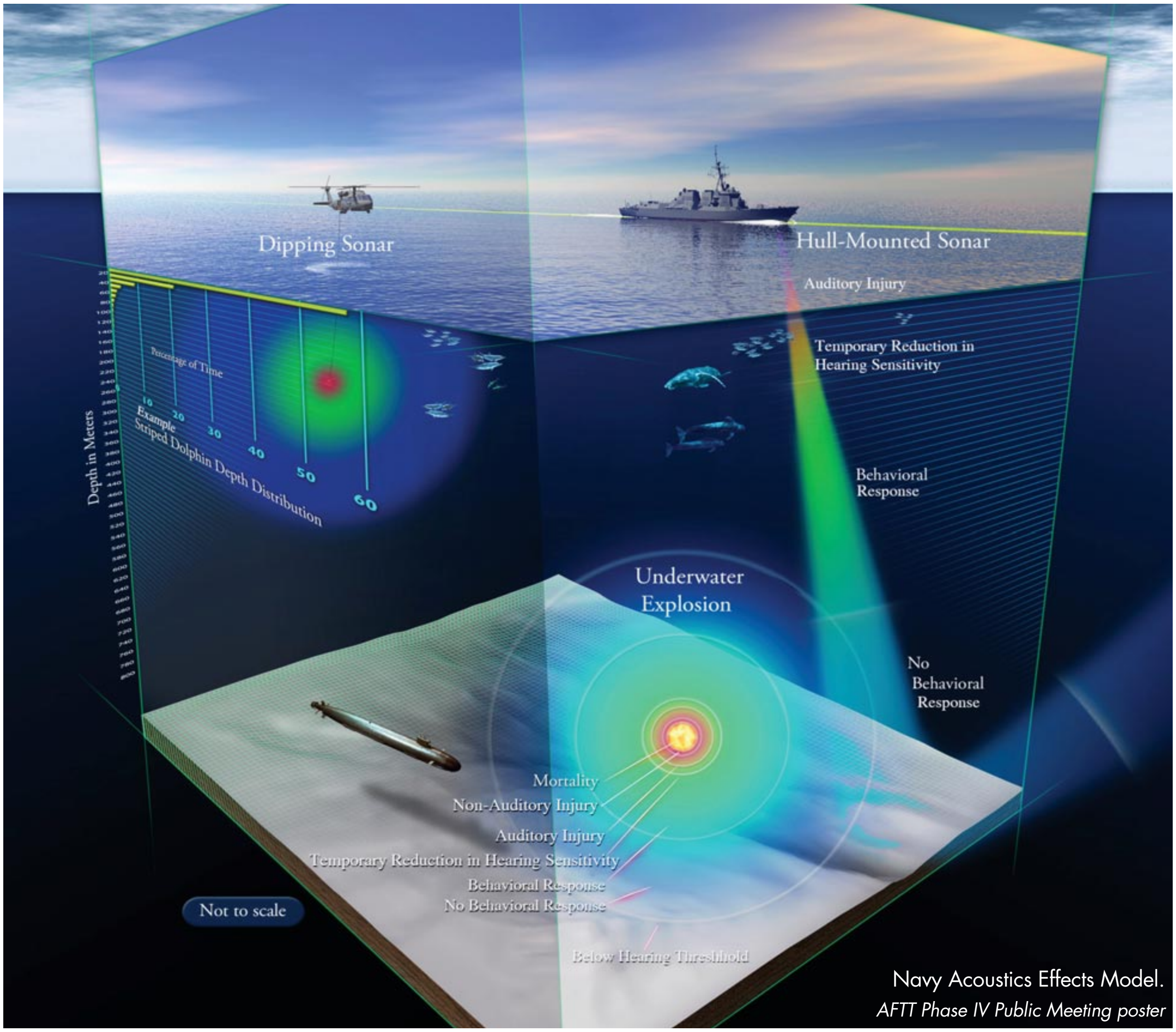
To assess the potential impacts of training and testing activities on protected marine species, the Navy uses the Navy Acoustic Effects Model (NAEMO). This acoustic modeling and simulation tool estimates potential impacts on protected and endangered marine mammals and sea turtles from underwater sound associated with Navy training and testing activities. Originally developed in the late 1990's, NAEMO has been updated periodically to reflect advancing technical and scientific knowledge. A recent scientific review and workshop identified several areas for needed improvements including further consideration of the sensitivity of the model to its inputs, the uncertainty and the overall robustness of the current modeling approach.

PROJECT

This project is conducting sensitivity analyses to consider which input parameters have the greatest influence on model outputs (and thus may be the subject of future research investment to improve estimates of effects). Uncertainty analyses will focus on how much the uncertainty in each input parameter influences uncertainty in the resulting model outputs. This also includes the estimation of a Monte Carlo error, which is an uncertainty that arises because it was computed using a finite number of simulated samples instead of the true, infinite distribution. Finally, robustness analyses, a type of sensitivity analysis, will be used to assess how sensitive model outputs are to different possible model formulations (as opposed to differences in parameter values within a model formulation).

This is a collaborative project between the principal investigators from St Andrews (led by SMRU Consulting) and the Marine Species Modeling Team (MSMT) from the Naval Undersea Warfare Center (NUWC) Division Newport. Each team will lead separate but closely related efforts. One will be primarily undertaken by the team at NUWC with support and input from St Andrews and one will be led by the St Andrews team, developed outside of the current NAEMO modeling processes but in consultation with MSMT NUWC. Within each effort, the project plan is organized around specific work packages as summarized below.

- **Work package one (WP1)—Monte Carlo error and sensitivity of NAEMO input parameters**
  The MSMT NUWC team will work to understand the size of the expected Monte Carlo error (uncertainty) and how that error changes. They also will work to identify other potential error components. Results will contribute to other work packages, specifically work package three (animat seeding) and work package four (simulation studies).
- **Work package two (WP2)—Simulator development**
  The St Andrews team will develop a simulator to understand which processes, and their formulation, are having the largest influence on estimated effects or on other metrics used to support compliance. The functional and efficient NAEMO simulator is intended to approximate the current NAEMO outputs but with increased flexibility to explore sensitivities of input parameters and processes within the model.
- **Work package three (WP3)—Animat seeding**
  This work package will explore how within NAEMO virtual marine animals (animats) are introduced and distributed (i.e., seeded) and when density is accounted for in the modeling processes. This will help to identify processes



Navy Acoustics Effects Model.
AFTT Phase IV Public Meeting poster

that could reduce simulation complexity, processing time and the size of the output file.

- **Work package four (WP4)—Simulation studies**
  This will include two phases of simulation studies. The first (WP4a) will explore animat movement in multiple dimensions, sound propagation complexity and sound avoidance and how these factors change the estimated effects compared with current NAEMO outputs. A second phase (WP4b) will then be undertaken to understand if, and how, to implement context-specific animat responses and whether such inclusion would improve overall compliance.

In 2025, the St Andrews team travelled to NUWC for a five-day work meeting to establish a detailed action plan and coordinate timelines. Subsequent 2025 work focused on Work Packages 1 and 2.

WP1 is being led by the Marine Species Modeling Team (MSMT) at NUWC. It is focused on characterizing the Monte Carlo error and sensitivity of NAEMO input parameters. With the short time available at the end of the year, the team explored sensitivity of model results to various components of behavioral response functions as well as to the use of different noise propagation models. In 2026 other sensitivities will be explored and the Monte Carlo error characterized.

WP2 is being led by the St Andrews team and involves developing a flexible simulator (currently being referred to as "BRUCE") to approximate NAEMO outputs with increased capacity to explore how different processes influence the estimated effects. By the end of 2025 three of the planned four simulator modules had been built and were being tested. These are modules for: 1) creating the modeling box, 2) modeling platform movement and 3) modeling animat movement. In early 2026 the final module (interaction between animats and platforms) will be completed, and the simulator performance will be evaluated against estimated effects outputs from NAEMO.

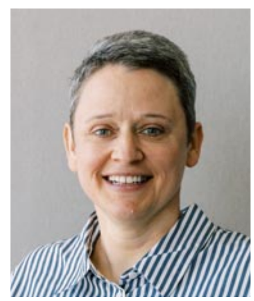
> Project outcomes will help to increase efficiency and reduce processing time of NAEMO analyses, providing cost savings to the Navy.

Later in 2026 work will commence on WP3 (led by NUWC) to explore the effects of changing the way animats are seeded in NAEMO, and on WP4 (led by St Andrews) using the simulator created in WP2 and sensitivities identified from WP1. Teams will conduct several rounds of simulation studies in a robustness analysis to explore how certain factors—animat movements in more than one dimension, sound propagation complexity and animal avoidance—change the estimated effects compared with current NAEMO output. This will help to indicate the most robust directions for future development of NAEMO.

A second multi-day visit of the St Andrews team to NUWC is planned for May 2026 to ensure a smooth transition from WPs 1 and 2 to 3 and 4.

Project outcomes will help to increase efficiency and reduce processing time of NAEMO analyses, providing cost savings to the Navy. Input parameters and modeling methods analyzed in WP1 will highlight those areas of NAEMO to be improved, ultimately providing more accurate results. Refined simulation capabilities will decrease processing/run times for future NAEMO simulations program runs. Additionally, improvements could increase responsiveness to new data and ensure use of best available science. Currently if new or corrected data are provided at the end of simulation runs, varying degrees of re-analysis are required depending on the change. Improved simulation tools could allow partial re-analysis, minimizing the additional level of effort and time demands of full re-analysis.

About the Principal Investigators



Samantha Simmons is a principal scientist with SMRU Consulting and previously served as the Scientific Program Director with the U.S. Marine Mammal Commission. Dr. Simmons earned her Ph.D. in ecology and evolutionary biology at the University of California, Santa Cruz.

Magda Chudzińska is a senior researcher with SMRU Consulting investigating potential effect of marine developments on marine mammal species. Dr. Chudzińska earned her Ph.D. from Aarhus University.

Key contributor: Len Thomas (Centre for Research into Ecological and Environmental Modelling (CREEM) and School of Mathematics and Statistics at the University of St Andrews).

Measurement and Quantification of Acoustic Energy Radiated into the Ocean from a Near Surface Airborne Explosion

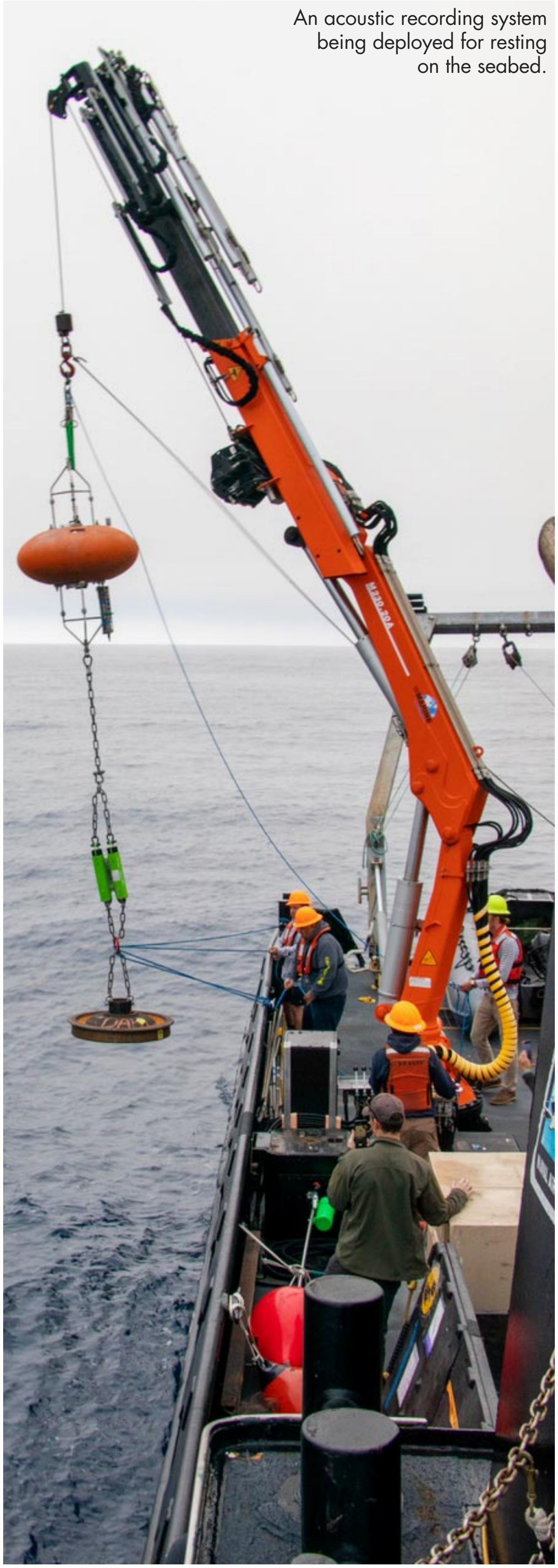
Principal Investigators:
David Dall'Osto, Peter Dahl
Project Status: New Start, Project 80

NEED

The Navy models the effects of explosions 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 subset of the types of explosive events that the Navy uses in training and testing activities. However, these data may not fully represent the sound source characteristics and propagation conditions that could be generated by larger explosions in more variable training and testing environments. In particular, data are needed for activities that involve in-air explosions occurring less than 10 meters above the sea-surface. Therefore, the Navy seeks to collect additional data on a broader range of charge sizes (from 20 to 250 lbs) and at a variety of distances/depths to improve the validation of the Navy's Acoustic Effect Model (NAEMO) explosive propagation, and to ensure that predictions of effects to marine species are as accurate as possible.

PROJECT

This project is working to characterize the acoustic field of Naval Air Systems Command (NAVAIR) operational ordinance deployed on the Point Mugu Sea Range. The project team, from the University of Washington Applied Physics Laboratory (APL-UW), will collect and provide to the Navy a set of well-documented and calibrated measurements of the underwater and airborne acoustic field produced by explosions that occur less than 10 meters above the surface of the water.



An acoustic recording system being deployed for resting on the seabed.

The initial field plan mirrors that employed in LMR Project 35, which was conducted in July 2023 to measure the propagation of explosions just under the sea-surface. The current project will reuse much of the equipment from that project.

As part of detailed field planning, the team will model airborne sound propagation, which will expedite the initial analysis and verify data quality. The modeling work will use data collected during Project 35 for verification.

To accommodate uncertainty around Sea Range operations scheduling, the team has built in deployment flexibility. This includes using a mix of drifting acoustic recorders, with sensors and recorders suspended below the surface float, as well as bottom-deployed recorders.

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

As currently configured, the sensors will be deployed both below the water at the source location and above water on surface buoys to document the sound field on both sides of the air-water boundary. The APL-UW team plans to distribute acoustic receiving devices within a 20-km range from the detonation, covering range and depth to fully measure propagation effects in the underwater sound field. Drifting receivers will be instrumented with satellite geo-tags to monitor buoy positions for search-and-recovery.

Data collected in the field in 2026 will be analyzed to provide a more thorough description of the airborne source coupling, which will be useful in developing a systematic model of the underwater noise generated by these airborne explosions. This analysis will provide a pathway to adapt the NAEMO predictions of underwater sound from such airborne explosive exercises.

The data collected directly apply to improving the accuracy and verification of NAEMO-based predictions of underwater sound fields from in-air explosives at both close and long ranges.

About the Principal Investigators

David Dall'Osto is a senior scientist and engineer at the Applied Physics Laboratory, University of Washington. His research focuses on modeling acoustic vector intensity and developing systems that sense the acoustic vector field in the ocean and atmosphere. Dr. Dall'Osto earned his Ph.D. in mechanical engineering at the University of Washington.

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

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. One partnership is summarized in this section.

- The Sonobuoy Liaison Working Group

Ongoing Partnership

Sonobuoy Liaison Working Group

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

Projects and organizations that receive sonobuoys are

1. Hawai'i marine mammal surveys—NOAA Pacific Islands Fisheries Science Center
2. NOAA Cetacean Assessment and Ecology Program—NOAA Marine Mammal Laboratory/Alaska Fisheries Science Center
3. Gulf of Mexico marine mammal surveys—NOAA Southeast Fisheries Science Center
4. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys—University of California at San Diego/Scripps Institution of Oceanography.

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

Sonobuoy inspection on an MH-60R Sea Hawk helicopter.
MC3 Gray Gibson

FORECAST

We look forward to even more accomplishments in 2026 and beyond. LMR will remain focused on meeting the Navy's need for research and technologies to sustain at-sea training and testing. New projects getting underway in 2026 include advancing the efficiency of the Navy Acoustic Effects Model (NAEMO), as well as collecting well-documented and calibrated measurements of the underwater and airborne acoustic field generated by a near surface airborne explosion. These projects will refine and validate the estimate of potential impacts to protected species from Navy training and testing activities. We will also collect new data to refine the Navy's acoustic effects criteria and thresholds from two projects including a behavioral response study to investigate the effects of continuous active sonar on marine mammals in southern California waters as well as a hearing study to investigate auditory temporary threshold shift in sea turtles.


Program Manager Anu Kumar and Deputy Program Manager Mandy Shoemaker.

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

We will continue working towards Phase II of the SURTASS LFA (Surveillance Towed Array Sensor System Low Frequency Active sonar) behavioral response study. We will be focused on configuring an appropriate sound source to support the work, which should be completed in 2027. Phase II field efforts are expected sometime in 2028.

Each of our projects was identified through our ongoing discussions with Navy end users to identify their most pressing research needs. These discussions will continue in the year ahead to reveal new need topics for LMR investment in 2027 and beyond.

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

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

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

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Note: Some citations are from projects completed prior to 2025.

Acronyms and Abbreviations

3S3/4 ......Sea mammals, Sonar, Safety project phase 3/phase 4
Argos ......A satellite-based system used for tracking data platforms (e.g., animal monitoring tags) in environmental monitoring
ARP ......Acoustic Recording Packages
BRS ......Behavioral Response Study
CalCOFI ......California Cooperative Oceanic Fisheries Investigations
CAS ......Continuous active sonar
CETACID ......Cetacean Caller-ID project
CEE ......Controlled exposure experiment
CREEM ......Centre for Research into Ecological and Environmental Modelling
CTBTO IMS ......Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System
DCL ......Detection, classification and localization
dB ......Decibels
DICAR ......DIrectional Cetacean Acoustic Recorder
DTAG ......Digital acoustic recording tag
ESA ......Endangered Species Act
GPS ......Global positioning system
HARP ......High Frequency Acoustic Recording Packages
HHMM ......Hierarchical Hidden Markov Model
IPR ......In-progress Review
kHz ......kilohertz
LIMPET ......Low Impact Minimally Percutaneous External-electronics Transmitter
LMR ......Living Marine Resources
LMRAC ......Living Marine Resources Advisory Committee
M3R ......U.S. Navy's passive acoustic marine monitoring data system
MFAS ......Mid-frequency active sonar
MMPA ......Marine Mammal Protection Act
MMRP ......Marine Mammal Research Program
MSM ......U.S. Navy Marine Species Monitoring Program
MSMT ......Marine Species Modeling Team
NAEMO ......Navy Acoustic Effects Model
NEPA ......National Environmental Policy Act
NAVAIR ......Naval Air Systems Command
NAVFAC EXWC ......Naval Facilities Engineering and Expeditionary Warfare Center
NCEI ......National Centers for Environmental Information
NIWC ......Naval Information Warfare Center
NMFS ......National Marine Fisheries Service
NMMF ......National Marine Mammal Foundation
NOAA ......National Oceanic and Atmospheric Administration
NSPE ......Navy Standard Parabolic Equation
NUWC ......Naval Undersea Warfare Center Newport
OBS ......Ocean Bottom Seismometers
ONR ......Office of Naval Research
ONR MB ......Office of Naval Research Marine Biology
OPNAV N4 ......Chief of Naval Operations for Fleet Readiness and Logistics
PACE ......Passive Acoustic Collection Engine
PAM ......Passive acoustic monitoring
PAS ......Pulsed active sonar
PCoD ......Population consequences of disturbance
PCoMS ......Population Consequences of Multiple Stressors
PI ......Principal investigator
PMRF ......Pacific Missile Range Facility
RDT&E ......Research, development, test and evaluation
SBIR ......Small Business Innovative Research
SDP ......Stochastic dynamic programming
SEL ......Sound exposure levels
SMRT ......Sound and motion recording and telemetry
SOAR ......Southern California Anti-Submarine Warfare Range
SPL ......Sound pressure levels
SYSCOM ......Systems Command
TB ......Terabyte
TRANSDEC ......Transducer Evaluation Center
TRC ......Technical Review Committee
TTS ......Temporary threshold shift
UC ......University of California
USFF ......U.S. Fleet Forces Command
UUV ......Unmanned underwater vehicle
VHF ......Very high frequency

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