LMR

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

2018

livingmarine RESOURCES

SCIENCE • STEWARDSHIP • NAVY READINESS

May 2019

2018 LMR Program Report

STATUS OF THE LIVING MARINE RESOURCES PROGRAM

TABLE OF CONTENTS

Note that any marine mammal photo in this report that does not explicitly include a photo credit/permit number came from a stock photo service.

PROGRAM INSIGHTS

I AM HAPPY TO SHARE WITH YOU the 2018 Living Marine Resources (LMR) Program Annual Report. Throughou the past year, the program and all of its participants continued their valuable work to support the Navy's ability to train, test and be mission-ready. Please see the Environmental Compliance Overview section (page 8) to learn more about how the LMR program supports the Navy's at-sea environmental compliance process.

The LMR program was managing 28 projects during 2018, all carefully selected to meet specific Navy-defined needs and provide additional scientific credibility to the Navy's environmental compliance analysis. Of the 28 projects, four were new, 18 were ongoing and six were completed during 2018 and are being transitioned to the end users. The four new efforts that started in 2018 are

1. TTS in Harbor Seals Due to Fatiguing Noise of Several Frequencies: temporary threshold shift onset sound exposure level (SEL) and growth curves for permanent threshold shift onset SEL estimation to set criteria (page 58)
2. Analytical Methods to Support the Development of Noise Exposure Criteria for Behavioral Response (page 68)
3. Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar (page 83)
4. Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources (page 87).

I also want to share highlights from two of the six completed projects to provide a sense of the scope of our work. One of these, *The Southern California Behavioral Response Study* (Project 02, page 21), obtained critical data on marine mammal behavioral response to Navy sonar, allowing us to develop a more robust scientific basis for estimating the effects of Navy training and testing. In fact, that project alone has produced over 35 scientific publications (thus far) and the methods continue to be transitioned to the Navy's Marine Species Monitoring Program for future studies. Another LMR completed project, *Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database* (Project 13, page 28), developed an American National Standards Institute (ANSI) standard for conducting a specific method to evaluate hearing in marine mammals. This allows the scientific community to collect comparable hearing data for use in the Navy's impact assessments.

Anu Kumar
Program Manager

Our other LMR projects are focused on advancing and applying knowledge to marine mammal tag technology, behavioral response research, acoustic recording devices and processing tools, and scientific standards for collecting and managing the data. We also continued our role in three ongoing partnership projects. See the Program Portfolio section (beginning on page 20) for more information on all of our projects.

Results from all of these current and past projects continue to contribute to the scientific literature that provides critical, well-founded scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) environmental planners, regulators, scientists and other stakeholders. Fifteen publications and technical reports, resulting directly from LMR-supported projects or using data from LMR projects, were produced and several more will be released in 2019.

I encourage you, through this report and our other communication channels, to learn more about the unique functions that the LMR program serves as the Navy's only marine species applied research program and about our close coordination with the Office of Naval Research's Marine Mammals and Biology Program and the Navy Marine Species Monitoring Program.

This work could not happen without our resource sponsor, the Chief of Naval Operations Energy and Environmental Readiness Division (OPNAV N45), and all the members of our management team, including the Fleet and SYSCOM representatives on the Living Marine Resources Advisory Committee. Your participation and support keeps the program focused on priority needs and well-coordinated with other Navy efforts. Thank you for all of your work. The program continues to be relevant and foundational to the current and future Navy mission because of your involvement.

Anu Kumar, Program Manager

PROGRAM OVERVIEW

MISSION

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

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

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

- Improving the best available science, regarding the potential impacts to marine species from Navy activities, available for use in at-sea environmental compliance documentation
- Demonstrating and validating basic research projects that are ready for applied research investment
- Broadening the use of or improving the technology and methods available to the U.S. Navy Marine Species Monitoring Program.

PROGRAM HISTORY

The LMR program traces its history back to the Navy's earliest efforts to better understand the impact of anthropogenic sound on marine mammals. In 1997, the scientific knowledge needed to establish an appropriate marine mammal monitoring and protection plan for Navy activities did not exist. The Navy initiated the Marine Mammal Research program, managed by Dr. Frank Stone at Chief of Naval Operations Energy and Environmental Readiness Division (OPNAV N45), to partner with other government agencies, universities and private industry to conduct scientific research required for monitoring and protecting marine mammals during Navy training and testing at sea.

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

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

Efforts were broadened in 2000 to include a new focus on the effects of mid-frequency sonar on beaked whales—the species thought to be most sensitive to that sonar.

Between 2000 and 2007, the Navy began work to identify what information would be needed to obtain

regulatory agency approvals for its major at-sea training ranges. In 2007, the research efforts were refocused to fulfill these information needs.

With a significantly expanded knowledge base, the distinctions among basic research (6.1 and 6.2 programs), applied research and testing (6.4 program) and the Marine Species Monitoring Program became more well-defined. (For more on the distinctions among organizations responsible for marine mammal efforts, see our section, "Navy Programs That Enable Environmental Compliance" on page 9) Thus in 2012, OPNAV N45 transitioned the funding line and formally designated the LMR program as the 6.4 applied research, development, test and evaluation (RDT&E) program, and restructured it to address the Navy's at-sea environmental compliance needs. While OPNAV N45 remained the resource sponsor, controlling the budget and final approval authority, the program needed dedicated management. A program office and manager were established at the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in Port Hueneme, California. This location allowed the program to manage and focus the increasing number of research needs, solicit and evaluate proposals, award contracts and provide end users the results they need.

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

In June 2014, Anu Kumar was hired as program manager, following Bob Gisiner's retirement. Mandy Shoemaker was selected to fill the deputy program manager position. The new team brought complementary skills and experience as subject matter experts in the Navy's environmental compliance process and associated scientific needs to carry the program forward. They have continued to refine the research needs evaluation and contract management processes to ensure that funds are efficiently expended on those projects of highest priority to the Navy. They have emphasized a collaborative atmosphere among the principal investigators executing the research and have enhanced end user involvement in the research products to ensure that those products address the original need. They also have continually worked to strengthen interagency and international cooperation, leveraging resources across related programs and optimizing limited funding resources. The highest priority is to transition successful products to the Navy's at-sea environmental compliance process in support of ensuring the uninterrupted training and testing needed for a combat ready force.

NAVY READINESS DEPENDS ON ENVIRONMENTAL COMPLIANCE

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

As part of the regulatory compliance process associated with these Acts, the Navy is responsible for assessing the potential impacts from military readiness activities.

The Navy is required to apply for environmental permits to conduct activities that may result in impacts to protected species regulated under environmental statues, such as ESA or MMPA.

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

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

Without permits and associated environmental compliance, the Navy risks not being able to train or test. Without training and testing, the Navy cannot be ready to meet its mission. Environmental compliance is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

NAVY PROGRAMS THAT ENABLE ENVIRONMENTAL COMPLIANCE

The U.S. Navy funds three main programs to support at-sea environmental compliance needs. These programs progress from basic research to applied research to monitoring implementation. The three programs are

1. The Office of Naval Research Marine Mammals and Biology program (ONR MMB)
2. The LMR program
3. The U.S. Navy Marine Species Monitoring Program

To promote ongoing coordination among the three programs, the program manager from ONR MMB and representatives from the Marine Species Monitoring Program are members of the LMRAC (described on page 12).

The Office of Naval Research Marine Mammals and Biology Program

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

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

Outcomes from this program are often transitioned to the LMR program to continue to develop, demonstrate and validate solutions, and then link products directly to an end user need. In some cases, outcomes can be transitioned directly to the Navy Marine Species Monitoring Program if ready for integration.

The Living Marine Resources Program

The LMR program is structured to focus on outcomes for Navy end users and to address the needs of the

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

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

- Collect and evaluate data on hearing abilities of marine species
- Conduct research on ESA-listed species other than marine mammals (e.g., fish, sea turtles, birds)
- Anticipate and conduct research on potential impacts resulting from new Navy sources (e.g., continuous active sonar)
- Demonstrate and validate technologies, tools, models and methods
- Develop standards and metrics for data collection or analysis

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

U.S. Navy Marine Species Monitoring Program

The U.S. Navy's Marine Species Monitoring Program is a requirement of the Navy's permits for training and testing. The primary objectives are to

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

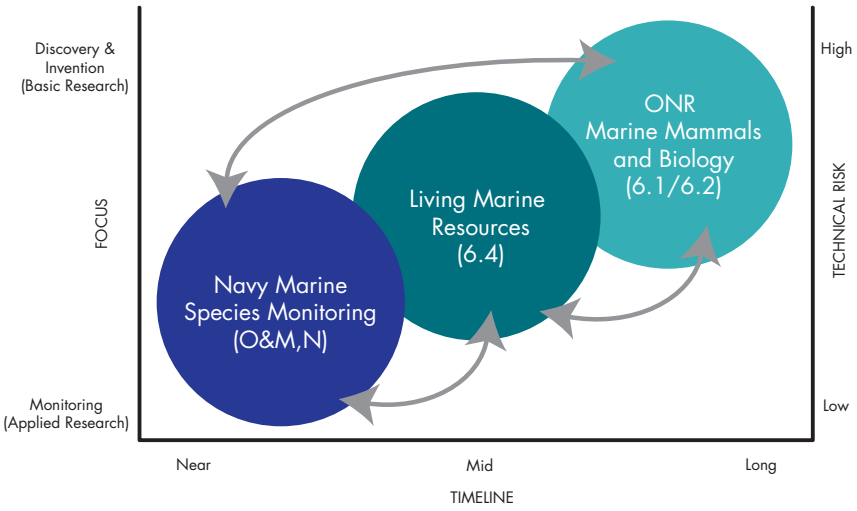
By providing a centralized program to address the Navy end users' stated needs, LMR provides a clear path for getting solutions and results to all who need them.

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

As the chart on the next page shows, there is significant interplay of projects and support among the three programs, yet each serves a distinct role in the compliance process. When an ONR MMB project is deemed ready to transition to the next stage of development, it might be selected for continued development, demonstration and validation within LMR. Following LMR-funded demonstrations and refinements, products can become reliable components of the monitoring program or results can be directly incorporated into environmental compliance documentation. In some cases, when a technology or method is ready for application, it will be transferred directly from ONR MMB development to the monitoring program. This coordination

among the programs supports successful transitions from basic research to the end user. The Marine Mammal Monitoring on Ranges (M3R) project, highlighted in the accompanying case study (M3R: Following a Technology's Development) is an example of this process.

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



M3R: Following a Technology's Development

The Marine Mammal Monitoring on Ranges (M3R) is an example of the interaction among the three programs that support at-sea environmental compliance. It also provides a technology benefit to the Navy's broader range monitoring effort.

The Office of Naval Research (ONR) initiated M3R in 2000 to investigate the possibility of leveraging existing Navy range hydrophones to monitor marine mammals. In 2009, the core M3R program was transitioned from ONR to LMR and prototype technologies were extended and used to study the predominant marine mammal species, particularly beaked whales, found on the Navy's instrumented ranges. Among its many contributions to monitoring, M3R proved to be valuable to on-water tagging by directing researchers to vocalizing animals. As of 2016, the core capabilities and operation of M3R were transitioned to the Navy Marine Species Monitoring Program for monitoring of vocalizing animals on all range hydrophones. ONR and LMR continue to pursue advancing research methods using M3R data to address new Navy needs. In addition, the data collected through this technology continue to be an important asset for several other ONR and LMR projects.

During early development, the M3R project designed a stand-alone Linux cluster base architecture that was subsequently adopted by the range operational community. The identical system architectures now employed by both the M3R and range tracking systems make it possible for the M3R system to serve as a development and test platform for the operational range system. This is helping the Navy to protect its long-term investment and reduce the maintenance costs for both systems.

STRUCTURE

The LMR program structure was carefully defined to ensure robust communication among Navy commands, other program managers and the LMR resource sponsor—OPNAV N45. The organization bolsters program communication, accountability and credibility.

Advisory Committees

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

LMR Advisory Committee

The LMRAC includes representatives from relevant Navy Fleet and SYSCOM activities affected by at-sea environmental compliance issues, as well as members of the Navy's research and monitoring community. The LMRAC includes representatives from

- OPNAV N45
- Office of the Deputy Assistant Secretary of the Navy for Energy, Installations and Environment (DASNE)
- Commander, U.S. Pacific Fleet (PACFLT)
- U.S. Fleet Forces (USFF)
- Space and Naval Warfare Systems Command (SPAWAR)
- Naval Sea Systems Command (NAVSEA)
- Naval Air Systems Command (NAVAIR)
- Naval Facilities Engineering Command (NAVFAC)
- ONR
- Office of the Oceanographer of the Navy (N2/N6E)

LMRAC members provide critical Navy end user perspectives on many program components including

LMRAC members provide critical Navy end user perspectives.

MCS2 Catherine Bland

defining needs, evaluating and ranking project proposals, participating in the annual In-progress Review and identifying transition pathways.

Technical Review Committee

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

Program Office

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

Resource Sponsor

The LMR program is sponsored by OPNAV N45 through its RDT&E Action Officer. Among its many roles as program sponsor, OPNAV N45 provides the LMR program's annual funding, sets policy and guidance for the Navy's environmental research priorities, approves the list of needs and authorizes new starts.

The program investment areas establish the broader boundaries within which the program works to achieve its mission.

PROGRAM INVESTMENTS AND PROCESS

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

1. Program investment areas
2. Navy needs
3. Priority species and geographic regions.

In addition, the program evaluates potential partnership efforts that can leverage program funds and contribute to the Navy's marine species knowledge base.

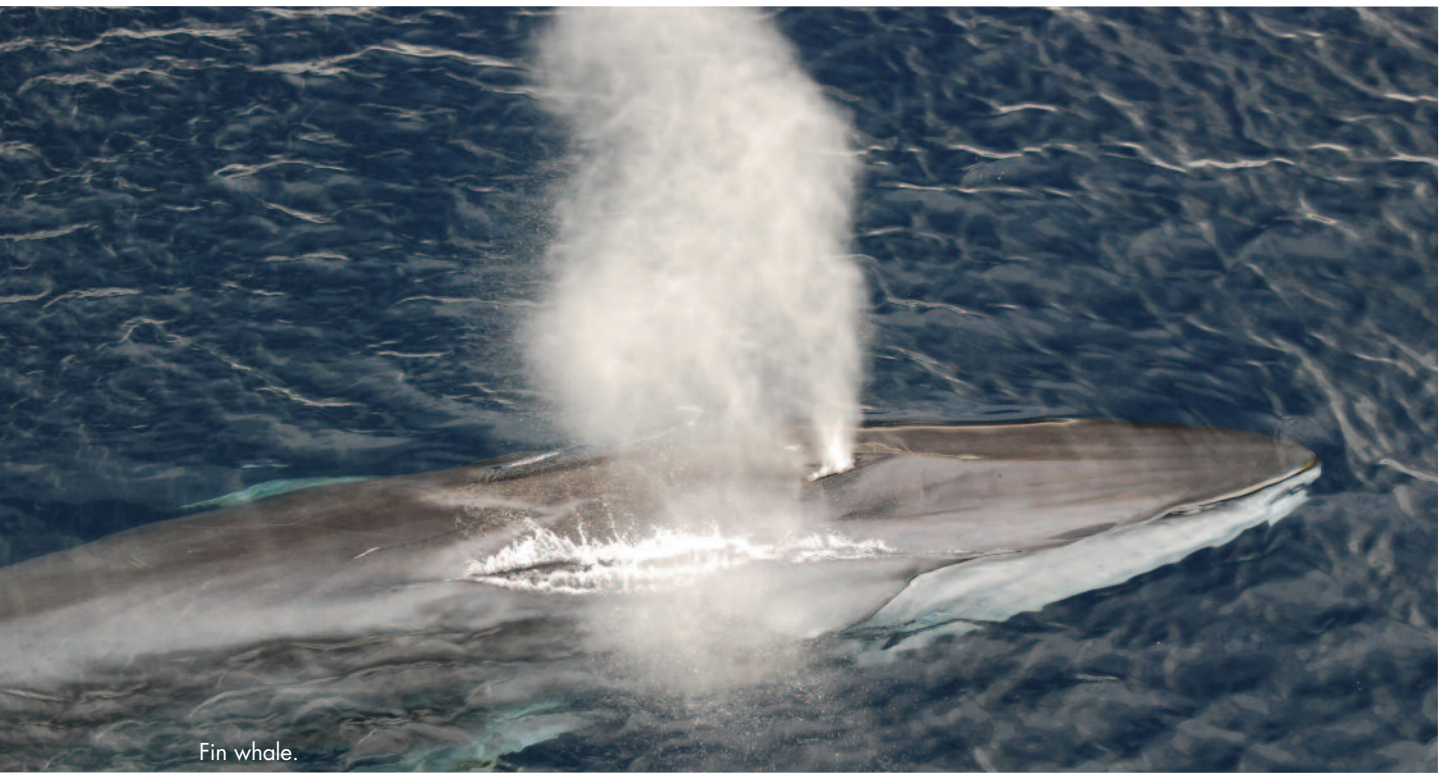
Program Investment Areas

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

1. Data to support risk threshold criteria.

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

Approach: obtain and analyze data on how well animals can hear, how and when animals may be exposed to acoustic and explosive sources, and how animals respond or are affected when exposed. The data are used to develop risk threshold criteria, inform the Navy's acoustic and explosive impact assessments and determine appropriate mitigation measures to reduce impacts to protected marine species. Projects in this



Fin whale.

area can include hearing studies, sound exposure and behavioral response studies.

2. Data processing and analysis tools.

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

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

3. Monitoring technology demonstrations.

Goal: to further develop technology to improve field data collection methods. Specific emphasis is given to utilizing existing Navy technologies and sensors for advancing environmental research and data collection. These technology investments enable efficient and cost-effective implementation of the Navy's Marine Species Monitoring Program to support the Navy's environmental compliance and permitting processes.

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

4. Standards and metrics.

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

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

5. Emergent topics.

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

Navy Needs

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

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

Anyone within the Navy may submit needs for consideration by the LMR program. For details on submitting needs, see the program website at navysustainability.dodlive.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 N45 resource sponsor.

LMR-sponsored projects are assigned within a need category. The need associated with a given project is identified in the project summaries presented in section 2 of the report, "Program Portfolio."

Priority Species and Geographic Regions

In addition to the program investment areas and the identified needs, the program also considers priority species and geographic regions when evaluating and

Humpback whale.
NOAA/NMFS

ranking proposals for program funding. While the program is interested in increasing knowledge and understanding of all marine mammal species, projects must be considered within the program's budget. In order to provide some guidance on research priorities, the priority marine mammal species for the program include

- Deep-diving species (Cuvier's beaked whale, other beaked whales, and other deep-diving species)
- ESA-listed species (large whales).

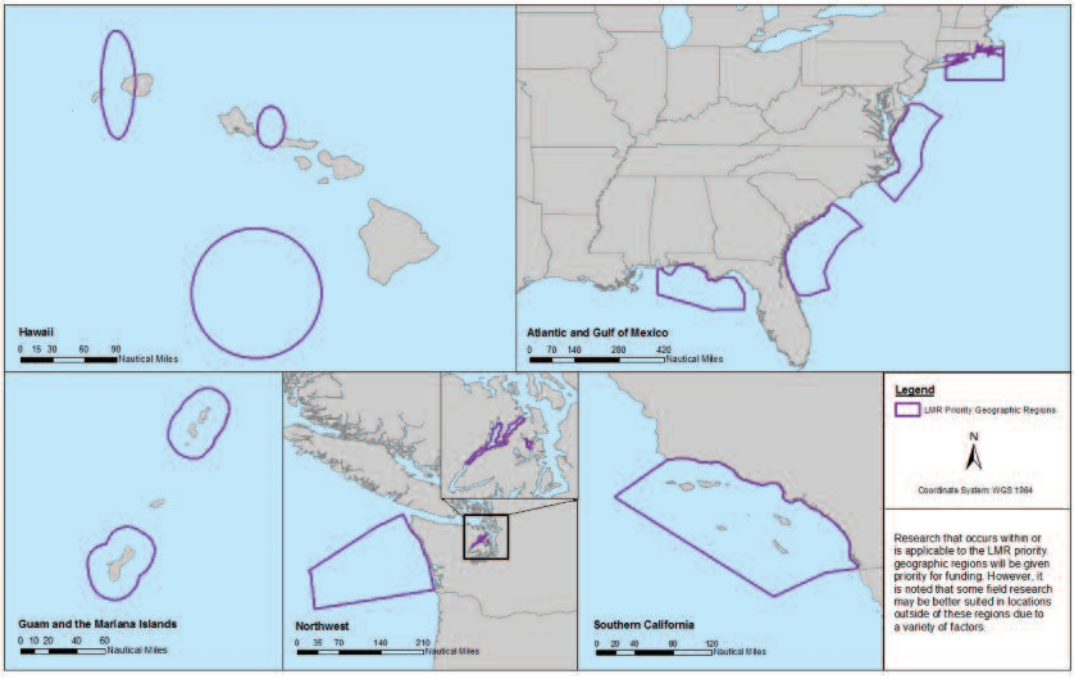
In addition to marine mammal species, the LMR program also is interested in increasing knowledge and understanding of the potential impacts to sea turtles, diving sea birds and fish when specifically identified as a priority Navy need.

The LMR program is primarily interested in funding research that is applicable to geographic regions that are important to the U.S. Navy. The map below shows the LMR program priority geographic regions. It is important to note that the LMR program acknowledges that a variety of factors could lead to some field research being conducted outside of these geographic regions, although results still apply to Navy needs within the regions.

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 Broad Agency Announcement (BAA) to solicit pre-proposals. After the BAA closing date, the proposal analysis process—conducted by the LMRAC, TRC and program staff—begins with a review to identify those pre-proposals of greatest interest for development into a full proposal, followed by a full proposal review and final recommendations to the program sponsor of projects to be funded.

Funded projects are initiated with a project kick-off communication between the principal investigator and program staff to discuss project and program expectations. Discussions cover details such as project milestones, spending plan and financial expectations, reporting requirements and ongoing communication



LMR Priority Geographic Regions.

The program works to move the demonstrated solutions out of research and into the hands of the appropriate Navy end users.

with program staff. The goal is to establish a framework that promotes project success and keeps projects targeted on meeting Navy needs.

When a project approaches its completion and its results demonstrate that an approach can successfully meet the Navy need, the program works to move the demonstrated solutions out of research and into the hands of the appropriate Navy end users. 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 integration. Some of the conditions that define successful integration include

- Project provides a feasible, desirable solution to the end user
- Stakeholders or end users have accepted and integrated the solution
- Funding has been planned for and is in place for transition, if necessary.

MANAGEMENT AND COMMUNICATION TOOLS

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

Quarterly Newsletters

The LMR program issues a quarterly newsletter, *LMR News*, to provide readers with the latest information about program operations, significant accomplishments, milestones and future investment areas for the LMR program. The digital newsletter can be viewed at the LMR website. Subscribers are notified by email when a new issue is available.

Project Highlights Fact Sheets

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

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

In-progress Review

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

LMR Website

The program website (navysustainability.dodlive.mil/lmr) serves as a centralized repository for public information about the program. The site offers ready access to the newsletter, project highlight fact sheets and annual reports. It also includes an announcement when a BAA is issued and provides information needed for pre-proposal submission related to the BAA.

The program website serves as a centralized repository for public information about the program.

MCS2 Ford Williams

PROGRAM PORTFOLIO

Projects & Partnerships

Completed Projects

Six projects were completed during 2018. Results from these projects are now available for use by the Marine Species Monitoring Program and those involved in environmental compliance.

1. Project 02 The Southern California Behavioral Response Study
2. Project 03 Simple Performance-characterized Automatic Detection of Marine Mammal Sounds
3. Project 12 Integrated Real-time Autonomous PAM System
4. Project 13 Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database
5. Project 15 Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments
6. Project 16 Passive Acoustic Density Estimation of Baleen Whales: Using Sonobuoys to Estimate Call-rate Correction Factors

The Southern California Behavioral Response Study

Principal Investigators:
Brandon Southall and John Calambokidis
Project Status: Completed, Project 02

NEED

N-0011-13 Behavioral Responses of Marine Mammals to Navy Sound Sources

Potential behavioral effects make up the largest and most poorly defined category of environmental risk from Navy sound-producing activities. The Navy needs data to strengthen the quantitative, statistical foundations of risk criteria thresholds used to assess potential behavioral effects from sound sources. Data collection can include controlled exposure experiments, opportunistic observations and laboratory studies.

PROJECT

The Southern California Behavioral Response Study (SOCAL-BRS) focused on cetacean (e.g., whales and dolphins) responses to simulated and operational Navy sonar. The overall objective was to increase understanding of marine mammal behavior and reactions to sound and to provide a more robust scientific basis for estimating the effect of Navy mid-frequency active sonar (MFAS) on marine mammal behavior. This project expanded upon, leveraged and is now informing many other Navy-funded marine mammal research efforts.

This expansive project included expertise from multiple institutions as visual observers, tagging teams, sound source engineers and acoustics biologists who conducted photo identification, passive acoustic monitoring, geographical information system (GIS) tool application, acoustic modeling and advanced biostatistical analysis. Field efforts were conducted from 2010 through 2016 in various coastal and offshore areas of the Southern California Bight.

Deploying high-resolution movement and acoustic archival tags on focal animals, the SOCAL-BRS generated one of the largest high-resolution data sets collected thus far for marine mammals. The project team achieved nearly 200 tag deployments on 10 federally protected marine mammal species, using well-established safety and mitigation protocols authorized under research permits. The SOCAL BRS employed both

Results were used in Phase III behavioral response curves and contributed to the Navy's impact assessments, supporting environmental compliance.

underwater acoustical monitoring methods and visual observers to monitor focal and other animals.

Controlled exposure experiments (CEEs) were a central component to measuring behavioral response. Conducted within well-defined protocols, the experiments used different sound types (simulated sonar, pseudo-random noise) from an experimental sound source or, when possible in coordination with Navy training activities, actual Navy tactical MFAS systems from surface ships or dipped from helicopters. This included nearly 100 discrete CEE sequences for individuals of seven marine mammal species. Lessons learned from these CEEs have helped to improve subsequent CEEs in other LMR projects.

Final project analyses were completed in 2018. Over 30 peer-reviewed publications have been produced thus far and five more are in review or preparation. These publications describe technological and methodological advances, provide baseline behavioral data useful in monitoring a number of key species, and deliver results that offer insights into the nature of behavioral response type and probability in the protected marine mammal species studied. Species for which data are being reported include blue whales, Cuvier's and Baird's beaked whales, fin whales, minke whales, sperm whales and Risso's dolphins. This project has reported unique behavioral observations of how these animals behave

A juvenile Risso's dolphin off southern California
Ari Friedlaender, NMFS permit 14534

Tagged Risso's dolphin in the SOCAL-BRS project.
Ari Friedlaender, NMFS permit 14534

in varied conditions, including how they move underwater, how they feed, how deeply they dive, how long they stay submerged.

The SOCAL-BRS continues to provide numerous Navy benefits. Results were used in Phase III behavioral response curves and contributed to the Navy's impact assessments, supporting environmental compliance. The project demonstrated a basic monitoring framework, new methods and a range of tools that are now being used by the U.S. Navy Marine Species Monitoring Program. Project results moved the state of the science beyond looking only at received levels to a wider range of factors—responses by species, what an animal is doing at time of exposure, its distance from a source, the source type and environmental variations.

The project's findings have major implications for effectively estimating potential impacts. They also inform subsequent research and monitoring efforts taking place using coarser methods over longer time scales. Project scientists are continuing to work directly with the Navy to transfer these findings into their environmental impact assessments and permitting processes.

About the Principal Investigators

Brandon Southall, BRS Senior Scientist, has been president and senior scientist for Southall Environmental Associates, Inc. since 2009 and is a research associate with the University of California, Santa Cruz and the Duke University Marine Laboratory. He has an extensive background in both laboratory and field research on the effects of noise on marine mammals and has published nearly 100 peer-reviewed articles on these topics. From 2003 to 2009, Southall directed the National Oceanic and Atmospheric Administration's Ocean Acoustics Program.

John Calambokidis, BRS Project Manager, is a senior research biologist and co-founder of the nonprofit Cascadia Research. He has directed long-term research on the status, movements and underwater behavior of blue, humpback and gray whales. His primary interests are the biology of marine mammals and the impacts of humans.

Project co-investigators: Peter Tyack, Design & Analysis (Woods Hole Oceanographic Institution/University of St Andrews); Jay Barlow, Passive Acoustics (National Oceanographic and Atmospheric Administration); and Dave Moretti, Sound Source (Naval Undersea Warfare Center).

Simple Performance-characterized Automatic Detection of Marine Mammal Sounds

Principal Investigator: David Mellinger
Project Status: Completed, Project 3

NEED

N-0020-13 Demonstration and Evaluation of Platform-Independent Improvements to Automated Signal Processing of PAM Data

As passive acoustic monitoring (PAM) sensors collect more and more data, the existing methods for processing the data prove to be time-consuming and costly. The Navy needs new PAM data processing tools that will increase efficiency, and are designed for users with relatively little or no subject matter expertise. In addition, there is a need for a process by which these tools are evaluated against common, shared benchmarks.

PROJECT

This project focused on enhancing the Ishmael (Integrated System for Holistic Multi-channel Acoustic Exploration and Localization) bioacoustic software package, by improving the software interface and developing training for users to facilitate use of automatic signal detectors and classifiers. These changes to Ishmael help technicians more efficiently detect and report marine mammal presence using acoustic data.

The Ishmael bioacoustics software program supports detection, classification and localization of marine mammals using acoustic signals. The program includes recording capability for real-time input, several methods for acoustic localization and automatic call recognition, and sound waveform and spectrogram displays.

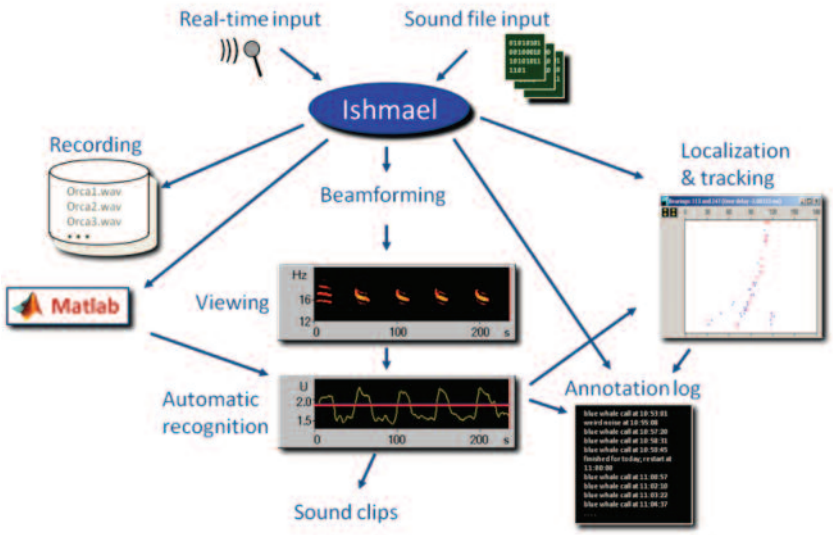
Following the initial development, supported by ONR MMB and NOAA, LMR supported efforts to

- Expand the networked detector archive
- Make it more accessible to users and
- Improve and update training and user materials.

During the project, the team added eight new species detectors, including ones of special interest to the Navy such as beaked, sperm and baleen whales. For each of these eight detectors, users can view performance information including receiver operating characteristic curve, detection error tradeoff curve and signal-to-noise distribution. Some detectors, as appropriate, reflect specific geographic and temporal differences (e.g., the mix of species in an area, call variations by area or over time, etc.). Users can access detectors online or can download them. The program also now includes links to the programming platform, MATLAB® to allow for custom script integration.

The project team conducted two well-received workshops, one in 2017 and one in 2018. Workshop attendees included Navy personnel, private (contractor) acoustic analysts, academics and regulators who analyze acoustic data.

Map from the detector archive showing detectors that are currently available.
Dave Mellinger



Incoming sound, either real-time or recorded, can be viewed and/or recorded, have detection/classification processes run on it, or be used to localize the marine mammals making calls.

The final year also completed extensive revisions to the Ishmael user's guide and produced an Ishmael tutorial for new users. Videos are also available to assist users. Examples of video topics include

- Making spectrograms
- Manipulating sound files
- Principles of detection
- Energy sum and detection functions
- Spectrogram correlation
- Matched filter
- Whistle and moan detector
- Evaluating performance
- MATLAB-Ishmael interface.

These improved support materials, along with a refined user interface, have made Ishmael far more accessible to a broader range of users. A user now can choose a species to monitor and have the system provide detections and other performance measures for the selected species. New detectors and classifiers can be added to the online database. By providing faster and easier analysis of acoustic data, Ishmael reduces the need for manual review and specialized staffing, which ultimately can reduce Navy monitoring costs.

These improved support materials, along with a refined user interface, have made Ishmael far more accessible to a broader range of users…which ultimately can reduce Navy monitoring costs.

Additional information about Ishmael, the user guide and links to videos are available at www.bioacoustics.us/ishmael.html.

About the Principal Investigator

Since 2000, David Mellinger has been a professor and researcher at Oregon State University. He is a specialist in marine mammal acoustics and developing algorithms and software for digital bioacoustic signal processing. Dr. Mellinger has a Ph.D. in Computer Science from Stanford University.

Integrated Real-time Autonomous PAM System

Principal Investigators:
Philip Abbot and Vince Premus
Project Status: Completed, Project 12

NEED

N-0006-13 Demonstration of Remote Passive Acoustic Sensing Technology

The Navy needs to be able to monitor sites of interest such as Navy training and testing areas. Passive acoustic monitoring (PAM) is a proven means of detecting, classifying, and localizing vocally active marine mammals, as well as a number of fish species. This need is focused on demonstration of existing PAM technology. Sensors can be moored, drifting, vessel-towed or mounted on unmanned mobile platforms, including gliders.

PROJECT

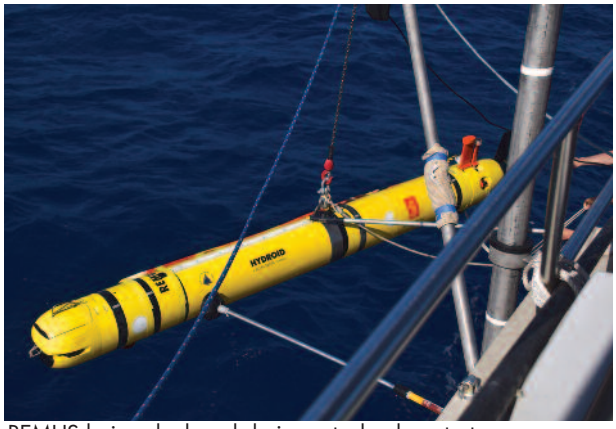
This project demonstrated the potential for a powered autonomous underwater vehicle (AUV), equipped with a passive acoustic sensor array, to provide improved acoustic monitoring and survey capabilities for Navy at-sea training and testing activities.

Low-cost, low-power commercial technology for acoustic remote sensing is enabling significant advances in autonomous undersea platform capabilities, including the use of hydrophone arrays. In this project, the principal investigators from Ocean Acoustical Services and Instrumentation Systems, Inc. (OASIS) integrated low- and high-frequency hydrophone arrays into a REMUS 600 AUV—operated by the Woods Hole Oceanographic Institution—for the detection, classification, localization and tracking of baleen whales and odontocetes. The system, known as the Integrated Real-time Autonomous Passive Acoustic Monitoring System (IRAP), offers a number of advantages relative to single hydrophone systems. In particular, using an array yields increased detection range and area coverage, as well as the potential for localization of signals.

These sensor and digital signal processing technologies have previously been demonstrated for passive acoustic marine mammal monitoring using Slocum 100 and G2 gliders. For this project, several factors supported demonstrating the technologies with the REMUS 600 autonomous platform. The REMUS 600 can travel faster than the other platforms—therefore covering more ground—and has the battery capacity to support deployment for several days. Being self-propelled, the REMUS can also operate in the presence of currents, following any predetermined course.

This technology, suitable for multiple platforms, is now available for the Navy's Marine Species Monitoring Program as an additional sensor package for monitoring presence and abundance of both high- and low-frequency marine mammal vocalizations.

The project integrated both sensors and detection classification and tracking software into an embedded low-power processor, then conducted end-to-end engineering tests and at-sea marine mammal surveys to demonstrate the system. The low-frequency sensor was integrated and tested in 2014. This included validating the humpback whale classifier. The high-frequency array



REMUS being deployed during a technology test.
Mandy Shoemaker

for beaked whales was then integrated into the system and, in July 2015, the performance of the overall IRAP device was tested in Monterey Bay in collaboration with scientists from the Naval Postgraduate School. To quantify system performance, recorded vocalizations of beaked and humpback whales were transmitted using calibrated, ground-truthed acoustic sources.

During 2016, the project team tested the real-time monitoring capabilities of the IRAP system at the Pacific Missile Range Facility (PMRF) off Kauai, in concert with the Submarine Command Course. The test demonstrated the IRAP system's potential, and quantified system performance in terms of array gain, tracking accuracy and detection range, while simultaneously monitoring the operation of U.S. Navy mid-frequency active sonars. The result was the first-ever detection and tracking of natural beaked whale clicks on an AUV-based high-frequency array.

A final platform demonstration on the Southern California offshore range (SCORE) was completed in early 2018. The team worked with the Space and Warfare Systems Center range tracking and the M3R (Marine Mammal Monitoring on Ranges) systems for real time localization. This information identified areas for the IRAP system operation and provided comparison with IRAP system observations. The system collected over 40 hours of high- and low-frequency sensor data, which included Cuvier's beaked whale detections that were confirmed in post-survey analyses.

The sensor and processing technology comprising IRAP can be employed on autonomous platforms including the REMUS 600, the SLOCUM G2 and the LRI Waveglider SV-3. Several comparison criteria—cost, availability, propulsion and navigation methods, energy source—have been assessed during the project period. Platform selection ultimately will depend on specific monitoring needs.

This technology, suitable for multiple platforms, is now available for the Navy's Marine Species Monitoring Program as an additional sensor package for monitoring presence and abundance of both high- and low-frequency marine mammal vocalizations. Deployed on an appropriate AUV, the system can provide an enhanced range of detection and capability to locate the animals.

About the Principal Investigators

Philip Abbot is president of Ocean Acoustical Services and Instrumentation Systems, Inc. (OASIS), a small business corporation providing consulting, research and design in ocean acoustics and related sciences. He holds a patent for methods and systems developed in connection with his ONR-sponsored work with AUVs. Mr. Abbot earned his master's degree in Ocean Engineering from the Massachusetts Institute of Technology.

Vince Premus is a principal scientist and vice president at OASIS, responsible for signal processing development and systems integration for autonomous sensing applications. Dr. Premus holds a Ph.D. in Electrical Engineering from Duke University.

Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database

Principal Investigator: Dorian Houser
Project Status: Ongoing, Project 13

NEED

N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

To understand whether sound from Navy activities is affecting marine mammals, it is necessary to understand more about their hearing. There is a need to compare hearing thresholds obtained with behavioral audiometric and Auditory Evoked Potential (AEP) methods. For AEP methods, electrode placement and different stimulus parameters will be required to obtain optimal evoked responses for the estimation of hearing sensitivity in different species. The Navy needs standardized hearing data collection methods in order to ensure that best available methods are used to obtain hearing data.

PROJECT

To understand whether sound from Navy activities is affecting marine mammals, it is necessary to obtain information about marine mammal hearing, including hearing thresholds. This multifaceted project focused on two primary goals: 1) generate an agreed-upon national standard for auditory evoked potential (AEP) hearing test methods used in odontocetes (toothed whales); and 2) support the development and implementation of the Evoked Response Study Tool (EVREST) to increase marine mammal species representation and sample sizes in hearing threshold estimates.

The hearing threshold, the lowest level of sound that can be detected by an animal at a specific frequency of sound, is important for understanding marine mammal hearing. An AEP is a voltage produced by the brain in response to hearing a sound. By measuring the AEPs at different sound levels, hearing thresholds can be obtained. With appropriate equipment, the voltages can be quickly measured with minimal subject cooperation. The measurements are used to produce audiograms of an animal's hearing range.

Standardized methods will help to ensure comparable hearing data for use in analyses conducted by the Navy as part of the environmental compliance process.

There are numerous methods by which AEP hearing thresholds can be determined and the method that is employed can affect the hearing threshold estimate. Differences might vary on the order of tens of decibels, which can have serious ramifications for determining the range of audibility for Navy acoustic sources, as well as for estimating impacts within mid- to low-frequency ranges where variances will be the greatest. For this reason, the Navy needs standardized AEP data collection methods to ensure that hearing threshold estimates are comparable across laboratories and researchers.

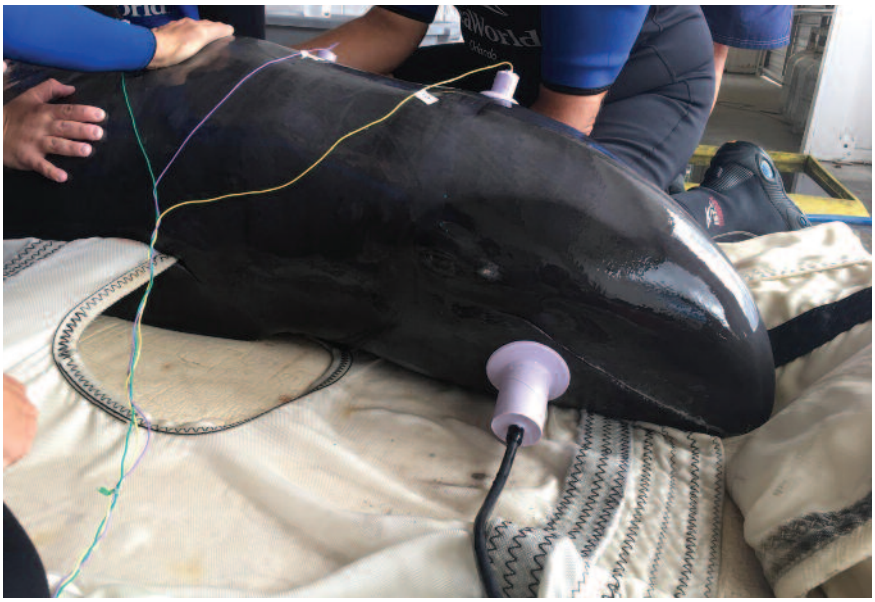
Efforts over the project life included

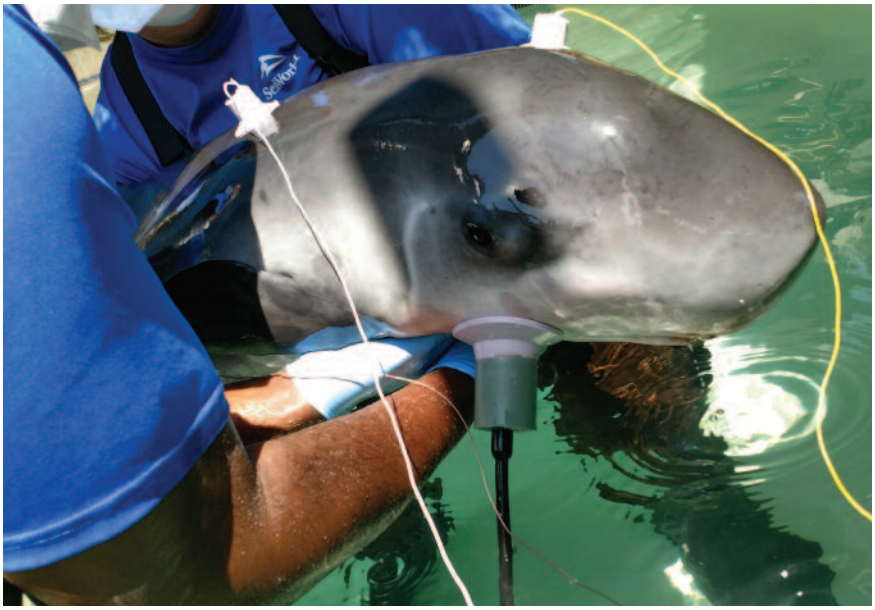
- Developing a standardized AEP methodology for approval by the American National Standards Institute (ANSI)
- Updating EVREST—the portable AEP system

currently used by stranding networks—to reflect the adopted ANSI standards

- Maintaining and improving existing EVREST systems, and
- Training and assisting stranding network personnel, which offers an important opportunity to collect hearing data from and generate audiograms for a wider range of species and to expand the sample sizes for a given species.

In 2018, the primary project goal was completed when the methodology was published as an American National Standards Institute (ANSI) standard entitled, "Procedure for Determining Audiograms in Toothed Whales through Evoked Potential Methods (ANSI/ASA S3/SC1. 6-2018)." The standard is the first of its kind and is not comparable to any existing ANSI or International Organization for Standardization (ISO) standard.





AEP hearing tests being conducted on a (top) pygmy sperm whale (*Kogia breviceps*) and a (bottom) melon-headed whale (*Peponocephala electra*).

D. Houser, NMFS permit 21026

The standard details how to measure odontocete hearing thresholds using a specific evoked potential method—the generation of the auditory steady-state response (ASSR). By measuring the ASSR at different frequencies and levels of sound, an audiogram can be produced for an animal. The two approaches to generating the ASSR are through the presentation of sinusoidally amplitude-modulated (SAM) tones or trains of tone bursts.

The standard covers many topics that can promote comparable results across laboratories and researchers, including

- General equipment requirements
- Stimulus waveforms for measuring hearing thresholds
- Acoustic stimulus waveform calibration
- Threshold estimation methods

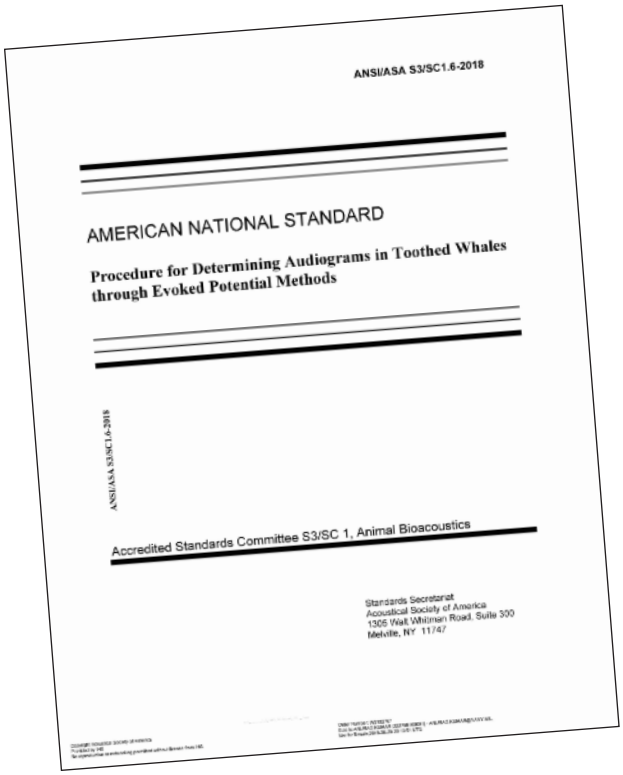
MCS2 Eli K. Buguey

- Results reporting formats
- Modulation rate transfer function determination
- Background noise considerations
- Testing arrangements, including types of electrodes and their placement.

Standardized methods will help to ensure comparable hearing data for use in analyses conducted by the Navy as part of the environmental compliance process.

The second goal of this project focused on EVREST—the portable AEP system produced by Dr. James Finneran of the U.S. Navy Marine Mammal Program. A new software version (EVREST DB) was completed that allows users to load species-specific settings and to modify amplitude modulation rates (critical for novel species). The project team updated the software to reflect the new ANSI standard, completed maintenance and updates of most existing EVREST systems and trained stranding network personnel to use the system.

Over the course of this project, twenty-eight AEP audiograms from nine different odontocete species were collected. These include multiple novel species (*Kogia breviceps, Lissodelphis borealis, Peponocephala electra*) and several findings of animals with hearing deficits. Stranding responders trained through the project collected many of these results. A parallel project, sponsored by NOAA, developed a national database for archiving AEP audiograms and metadata. The database will benefit Navy by providing ready access to all available AEP data.


ANSI/ASA S3/SC1.6-2018

AMERICAN NATIONAL STANDARD

Procedure for Determining Audiograms in Toothed Whales through Evoked Potential Methods

ANSI/ASA S3/SC1.6-2018

Accredited Standards Committee S3/SC 1, Animal Bioacoustics

Standards Secretariat
Acoustical Society of America
1305 Walt Whitman Road, Suite 300
Melville, NY 11747

Cover of the ANSI standard.

About the Principal Investigator

Dorian Houser is the director of conservation and biological research at the National Marine Mammal Foundation. Dr. Houser has spent nearly two decades in the study of how anthropogenic sound affects marine mammals and has been involved in the development of numerous environmental impact statements for the U.S. government. He earned his Ph.D. in Biology from the University of California, Santa Cruz.

Common dolphin.
NOAA/NMFS

Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments

Principal Investigators:
Ted Cranford and Petr Krysl
Project Status: Completed, Project 15

NEED

N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

To understand whether sound from Navy activities is affecting marine mammals, it is necessary to understand more about their hearing. There is a need to compare hearing thresholds obtained with behavioral audiometric and Auditory Evoked Potential (AEP) methods. For AEP methods, electrode placement and different stimulus parameters will be required to obtain optimal evoked responses for the estimation of hearing sensitivity in different species. The Navy needs standardized hearing data collection methods in order to ensure that best available methods are used to obtain hearing data.

PROJECT

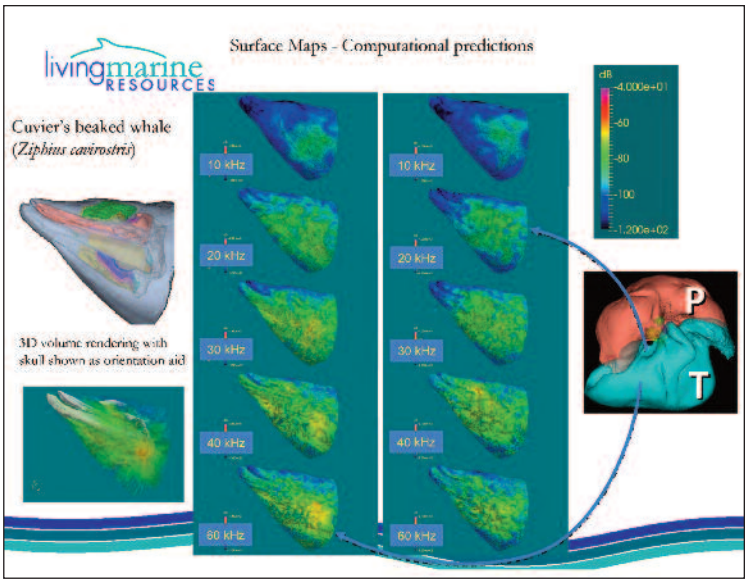
One of the methods researchers use to collect hearing data is measuring voltages produced by the brain's response to an acoustic stimulus. These voltages, called AEPs, can be quickly measured in subjects using specialized equipment. This project used a computational approach to identify the mechanism(s) by which the device used to deliver the sound actually stimulates hearing. Understanding the mechanisms could improve how the devices are used and improve the resulting measurements.

The device used to deliver sound directly to an animal for AEP measurements is called a jawphone, which is a suction cup containing a transducer. Factors related to how the device is used can influence the final test results, including where the jawphone is positioned on the animal, the frequency selected and other parameters. In preliminary simulation studies, it appears that jawphones can selectively excite hearing pathways that may be different from those used naturally by the animals. Simulations indicate that small changes in the placement of a jawphone can cause large amplitude differences (several decibels) by the time the sounds reach the ears. Currently, most field methods using AEP attempt to account for this in their protocol for known species. However, for untested species, this is an important factor to consider for future investigations.

> …guidance for jawphone placement that can be obtained from these models…will be particularly useful when measuring the hearing capabilities for species not yet studied.

This project used finite element modeling techniques, in which high-resolution computerized tomography (CT) scan data are combined with measurements of tissue properties and custom-built computer programs to simulate sound propagation into and out of the anatomic geometry of specimens. Model outputs quantify the acoustic pathways between the jawphone and the ear, which are used to develop sensitivity maps that identify the optimal locations for jawphone placement in three marine mammal species. These sensitivity maps can be used to design and evaluate AEP-based hearing tests, taking into account potential variable response sensitivity to the location of the transducer on the animal's skin. The maps can help to guide jawphone placement in order to achieve more accurate and consistent results.

This project produced surface sensitivity maps for three odontocete species, the common dolphin (*Delphinus capensis*), the bottlenose dolphin (*Tursiops truncatus*) and Cuvier's beaked whale (*Ziphius cavirostris*). These surface maps have been generated for six different frequencies at different sound source locations on the left side in all three specimens. The results suggest that while the maps display similarities, they vary in their details between the species and across the frequencies tested. The simulations performed for the bottlenose dolphin confirmed previous work that showed the details of anatomic geometry have implications for acoustic function. In addition, surface maps for phase shift and time delay show significant consequences for sound reception mechanisms and optimal placement of jawphones.



Researchers also evaluated potential differences in two primary conditions under which jawphones are used for AEP testing—in-air or in-water. Results showed that the surface maps were different for in-air and in-water, which may have implications for jawphone use. Initial results from the surface maps suggested that there are multiple mechanisms for sound reception in odontocetes. It is possible that a bone conduction mechanism in odontocetes serves to process low-frequency acoustic signals. A manuscript summarizing results from this project has been submitted for peer review.

In 2018, a follow-on validation experiment with a live dolphin at University of Hawaii was initiated. This experiment measured the sound pressure levels (SPL) received and the time delays at given receiver locations to calculate how SPL received varies based on changing the location of the sound source. Validating the computational determination of the sound reception mechanisms are expected to increase confidence in guidance for jawphone placement that can be obtained from these models. This will be particularly useful when measuring the hearing capabilities for species not yet studied. Data collection is complete, but analyses are still underway. Results from the validation experiment are expected in 2019.

About the Principal Investigators

Ted Cranford is an adjunct professor of research at San Diego State University Research Foundation. He earned his Ph.D. in Biology at the University of California, Santa Cruz. His interests include functional morphology, marine mammal science, bioacoustics and ecomorphology.

Petr Krysl is a professor of computational mechanics at the University of California, San Diego, Department of Structural Engineering. He holds a Ph.D. in Theoretical and Applied Mechanics from the Czech Technical University in Prague. His interests include finite element method development as applied to biomechanics, mesh generation methods and high-performance computing.

Passive Acoustic Density Estimation of Baleen Whales: Using Sonobuoys to Estimate Call-Rate Correction Factors

Principal Investigator: Shannon Rankin
Project Status: Ongoing, Project 16

NEED

N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data

The Navy needs to be able to derive improved density estimates for species of concern using Passive Acoustic Monitoring (PAM) data collected at sites of high Navy interest. Density estimation from PAM data requires a high level of data collection planning, metadata collection and external calibration of detection rates. The Navy needs a methodology that would include planning of a survey, collection of data and development of analyzed density data products that can be incorporated into the Navy Marine Species Density Data (MSDD) archive.

PROJECT

This project was originally designed to demonstrate a novel approach to estimating baleen whale density by applying a correction factor to call data. Although passive acoustic monitoring can capture whale calls, the number of calls is not directly equivalent to the number of animals in the area sampled. The underlying project concept was to develop a correction factor (or multiplier) that could be used to convert call density data to whale density. The project was designed to add PAM data collection using sonobuoys during National Marine Fisheries Service (NMFS) visual line-transect shipboard cetacean surveys to estimate call density for specific baleen whale calls. As whale density for these visual surveys is known (estimated with a narrow confidence interval), a multiplier could be estimated that would translate the estimated call density (from the sonobuoy data) to the whale density estimated from visual survey for the survey region. This multiplier could, in theory, be applied to novel sonobuoy data (collected on the same call types in the same region at the same time of day during the same time of year) to estimate the whale density in that area. In theory, this approach would allow researchers to estimate whale density in an area of concern in a timely manner.

In order to estimate call density from sonobuoys, the team

- Identified appropriate data collection methods
- Identified appropriate acoustic analysis methods and
- Identified and tested an appropriate statistical approach for estimating call density.

Playback experiments, conducted to examine effects of sonobuoy calibration and bearing angle estimation on density estimates, identified several sources of error. To address this, a specific protocol was developed with recommendations for sonobuoy deployment, calibration and drift calibration.

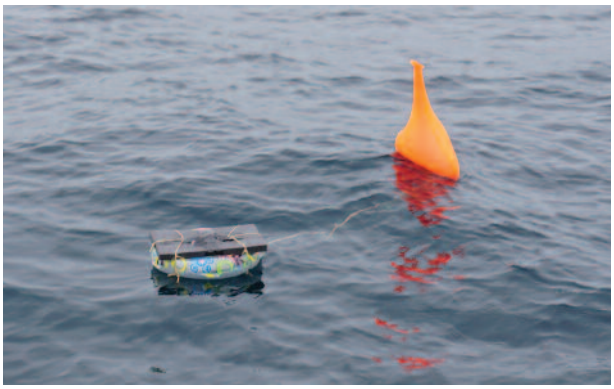
> The recommendations from this project will help to improve both the collection and the analysis of marine mammal acoustic data from sonobuoys.

Subsequent work focused on analyzing existing data, identifying issues and suggesting improvements. Methods to estimate bearing angles arising from using the directional low-frequency analysis and recording (DIFAR) software module in PAMGuard were prone

On board ship, monitoring signals from the deployed sonobuoys.

to errors. An alternative approach, developed by Aaron Thode at Scripps Institution of Oceanography, helped to alleviate many of the problems associated with methods of DIFAR bearing angle estimation. This alternative method allowed for simple examination of the background noise, improved detection and improved bearing angle estimation.

A statistical approach for estimating call density, called acoustic spatial capture recapture (ASCR), was investigated. A test of simulated data provided an estimate of the expected error for calls for different call densities and hydrophone spacing. Simulations suggest that ASCR is an appropriate method for estimating call density from arrays of two or more sonobuoys. Application of these methods will require that data are collected according to the protocol identified, bearing angles are accurate for all calls (including low signal-to-noise-ratio calls), the call densities are sufficiently high, and that calls are appropriately matched across detectors.



Sonobuoy with satellite tag float.

Due to the large number of unexpected problems encountered, this project served as a 'proof of concept' for density estimation using sonobuoy data. The development work completed under this project can be used to improve analysis of sonobuoy data in general. A final report was completed in early 2018 that documented a summary of best practices, including suggested changes to data collection, acoustic software modification; and identified analytical approaches appropriate for working with arrays of sonobuoys.

The Navy's supply of sonobuoys for marine mammal research provides the opportunity to collect data on marine mammal calls. The recommendations from this project will help to improve both the collection and the analysis of marine mammal acoustic data from sonobuoys.

About the Principal Investigator

Shannon Rankin has worked as a wildlife research biologist with NOAA's Southwest Fisheries Science Center since 2000, studying marine mammal sounds and using passive acoustic monitoring for population studies. She has a Master of Science in Wildlife & Fisheries Sciences from Texas A&M University, where she studied the effects of sounds from seismic exploration on marine mammal populations.

Ongoing and New Start Projects by Investment Area

INVESTMENT AREA 1: DATA TO SUPPORT RISK THRESHOLD CRITERIA

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

Risk threshold criteria are values that estimate the likelihood that certain types of specified effects will occur.

This information is obtained by collecting and analyzing data pertaining to 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. These data are then used to develop 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. Risk threshold criteria are also used to produce estimates of range to effects to help determine appropriate mitigation measures to reduce impacts to protected marine species. Improving the accuracy of range to effects estimates will reduce overly burdensome mitigation requirements that can reduce training and testing realism.

Projects in this area can include hearing studies, sound exposure and behavioral response studies. The following section includes summaries of ten projects: nine ongoing projects and one new project started in 2018.

Ongoing

1. Project 20 Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises
2. Project 22 Hearing and Estimated Acoustic Impacts in Three Species of Auk: Implications for the Marbled Murrelet
3. Project 23 Cuvier's Beaked Whale and Fin Whale Behavior During Military Sonar Operations: Using Medium-term Tag Technology to Develop Empirical Risk Functions
4. Project 24 Frequency-dependent Growth and Recovery of TTS in Bottlenose Dolphins
5. Project 25 A Blainville's Beaked Whale Behavioral Risk Function for Hawaiian Populations
6. Project 26 The Effects of Underwater Explosions on Fish
7. Project 29 3S3: Behavioral Responses of Cetaceans to Naval Sonar
8. Project 30 Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar
9. Project 32 Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

New Start

1. Project 33 TTS in Harbor Seals Due to Fatiguing Noise of Several Frequencies

Ongoing Projects

Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises

Principal Investigator: Ron Kastelein
Project Status: Ongoing, Project 20

NEED

N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

To understand whether sound from Navy activities is affecting marine mammals, it is necessary to understand more about their hearing. There is a need to understand how signal characteristics other than frequency may also affect the hearing, behavior, and physiology of marine mammals. 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

A variety of Navy sonar sources are audible to harbor porpoises (*Phocoena phocoena*), a small odontocete species that has a wide distribution area in the Northern Hemisphere. Because of limited available data on this species, predictions of temporary threshold shift (TTS) or behavioral response previously have been derived from surrogate, mid-frequency cetacean species exposed to other sound sources (e.g., airguns). Therefore, these predictions of impacts might be inappropriate for harbor porpoises. Behavioral response and TTS data specific to harbor porpoises are needed to improve estimates of potential effects on porpoise hearing and behavior from exposures related to Navy training and testing activities.

This project consists of two study types to collect the necessary data: a behavioral dose-response study and a TTS study.

The behavioral dose-response study has included two phases:

1. Establish the dose-behavioral response relationship for playbacks of 53-C sonar sounds at two duty cycles (2.7 and 96 percent) in quiet conditions
2. Establish the dose-behavioral response relationship for playbacks of 53-C sonar sounds at 96 percent duty cycle in high ambient noise condition. This is to assess how ambient noise might influence perception of sonar sounds and resulting behavioral effects.

> The results of the behavioral dose-response and TTS studies will be used to update the [Navy's] criteria and thresholds for harbor porpoises.

All data for both behavioral response studies were collected by the end of 2016. Phase one analyses were published in *Aquatic Mammals* in 2018. Results showed that no responses could be elicited in the porpoises due to exposure to 53-C sonar playback sounds at a duty cycle of 2.7 percent at the highest sound pressure level possible without causing unwanted harmonics in the testing environment. At the 96 percent duty cycle, one of the two animals showed increased respiration and moved away from the transducer.

Analyses of phase two data are complete and a manuscript was submitted for publication in late 2018. Results suggest that for the 53-C sonar signals tested and for harbor porpoises, a noise needs to be louder

ABOVE and AT RIGHT: Porpoise Flow with fish and transducer.
Lean Helder-Hoek

than that of Sea State 6 for it to mask the sonar signal and increase the sound pressure level at which a behavioral response occurs.

The TTS study consists of three phases:

1. Establish the audiograms of the two study animals. Because the animals arrived at SEAMARCO (Sea Mammal Research Company, Inc.) just before the start of the studies for LMR, their basic hearing thresholds needed to be established.

2. Study TTS in harbor porpoises from exposure to 53-C sonar playback sounds (3.5-4.1 kHz) at 96 percent duty cycle with exposure durations of 30 and 60 minutes. (Note that this approach is being used because TTS could not be established with exposure to 53-C sonar playback sounds at a duty cycle of 2.7 percent at the highest sound pressure level that could be produced in the pool. This is due to the low acoustic energy per time unit and the fact that the ear could also recover during the long inter-pulse intervals (one 1.6 second sonar signal every 60 seconds).)

3. Establish equal TTS curves for the entire harbor porpoise hearing range, incorporating data from the following frequencies: 0.5, 16, 32, 63 and 88.4 kHz.

Measuring the sound pressure level distribution in the porpoise pool.
Ron Kastelein

Results of the first two phases of the TTS study were published in the *Journal of the Acoustical Society of America* during 2017. The first publication included audiograms for the two animals. The second publication included results of TTS phase two, which showed that the initial (1-4 min) TTS measured at 4 kHz (96 percent duty cycle) was around 5 dB.

Phase three, collecting data and establishing equal TTS curves over the entire hearing range, began in 2017 and continued through 2018. Three of the five frequency levels have been tested, with data collected and analyzed. The manuscript for the 16 kHz tests has been submitted for publication, while manuscripts for the 32 kHz and 63 kHz tests are in preparation. Data collection for the 88.4 kHz frequency is nearly complete. The 0.5 kHz frequency testing was delayed but began in late 2018.

The results of the behavioral dose-response and TTS studies will be used to update the criteria and thresholds for harbor porpoises that are used to estimate potential exposures from Navy training and testing activities.

About the Principal Investigator

Since 2002, Ron Kastelein, Ph.D. (University of Wageningen, The Netherlands) has been director and owner of SEAMARCO in The Netherlands. SEAMARCO specializes in applied acoustic research with marine fauna (mammals, fish, turtles and invertebrates).

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

Principal Investigator: Aran Mooney
Project Status: Ongoing, Project 22

NEED

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

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

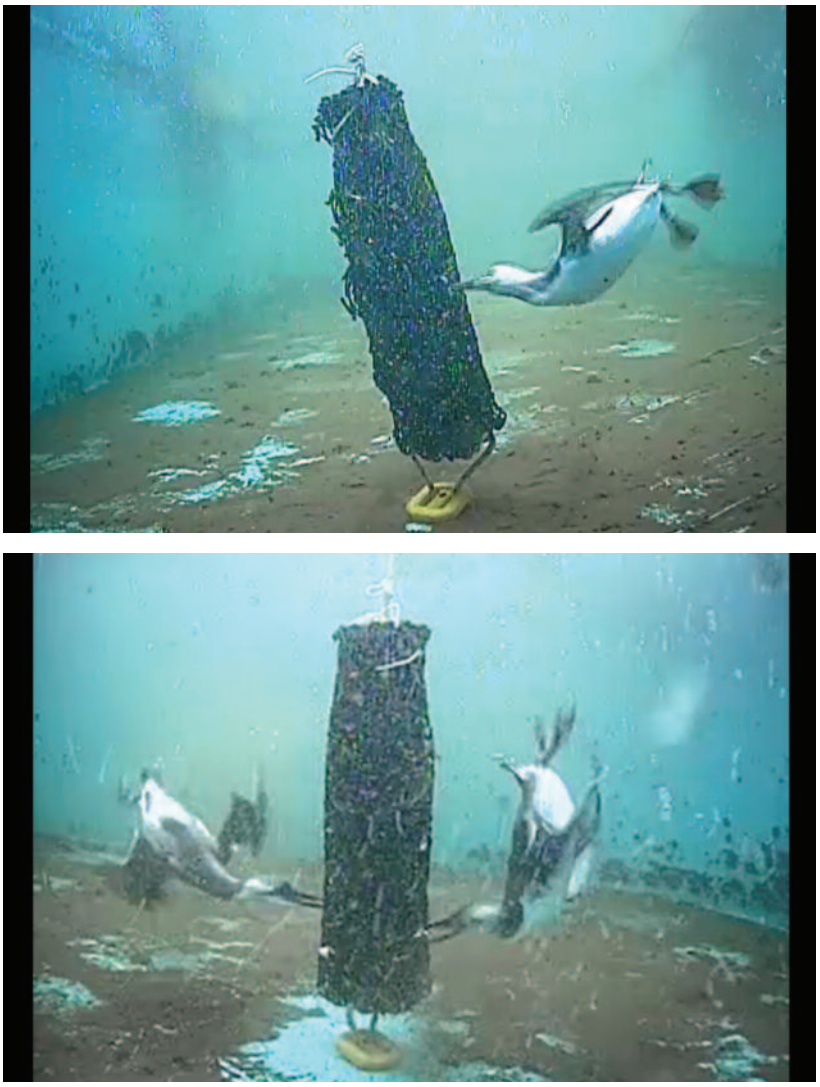
PROJECT

Some Navy readiness activities occur in areas that overlap with the natural habitat of the marbled murrelet (*Brachyramphus marmoratus*), a member of the auk (or Alcidae) family that is listed as threatened under the Endangered Species Act in Washington, Oregon and California, and state-listed as endangered in California. Potential effects from sound-producing activities might include auditory impacts such as temporary and permanent hearing threshold shifts as well as behavioral effects. Yet there currently are no basic data on the hearing of marbled murrelets or any other auk species. Current impact assessments and mitigation measures for birds are based on fish or marine mammal data, which is resulting in unrealistic mitigation zones. Therefore, the Navy needs data to improve impact assessments and validate associated mitigation zones related to birds.

This project is defining the hearing of up to three auk species—related to but not including the marbled murrelet—to provide data needed to predict the marbled murrelet's hearing. Over the course of the project, researchers will conduct both auditory evoked potential (AEP) methods and behavioral audiometric methods. Planned data collection efforts include in-air AEP tests, in-air behavioral audiometry tests and underwater behavioral audiometry tests. These tests will allow researchers to compare AEP and behavioral audiometric methods and to compare in-air and underwater measurements. The resulting audiograms will provide the data and training foundation for a temporary threshold shift (TTS) response feasibility study. In addition to AEP and behavioral audiometry testing, the team also will pursue anatomical testing as available.

> The project will provide key hearing data needed to support refining acoustic criteria for the marbled murrelet.

During 2018 the project team continued analyzing the AEP data they collected from the Atlantic puffin (*Fratercula arctica*) and common murre (*Uria aalge*) during 2017. They completed and submitted a manuscript on the field AEP methods used during their fieldwork, which includes preliminary audiogram data. (The field-based AEP tests—widely used rapid hearing test methods—involve measuring small voltages that the brain and auditory nervous system generate in response to sound.) The manuscript has been accepted by the *Journal of Experimental Biology* and should be out in early



Common murres at a feeding station during underwater audiogram training.
GoPro photos provided by Kirsten Anderson Hansen

2019. The 2018 AEP field work included audiograms on ten puffins, with data analyses underway.

Murre training for lab-based in-air behavioral audiometric tests was well underway in 2018. For these tests, the trained animals perform a specific behavior in response to sound. The team also conducted training and baseline trials for the underwater playback study. This is the first step needed to address if birds hear (and respond) to sounds underwater.

As hoped, the project team was able to conduct anatomical scans of auk ears. The scans, done repeatedly to improve confidence in results, will help researchers to document how comparable the ear structures are across species. Fifteen micro computed tomography (microCT) scans completed in 2018 provided data on puffins, common murres and dovekies (*Alle alle*). The team will complete more scans as samples are available.

The project will provide key hearing data needed to support refining acoustic criteria for the marbled murrelet. This will allow the Navy to improve the assessment of potential impacts on birds from training and testing activities and will result in more realistic mitigation zones.

About the Principal Investigator

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

Key collaborators include Marianne Rasmussen from the University of Iceland and Magnus Wahlberg from the University of Southern Denmark.

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

Principal Investigator:
Greg Schorr and Erin Falcone
Project status: Ongoing, Project 23

NEED

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

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

PROJECT

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

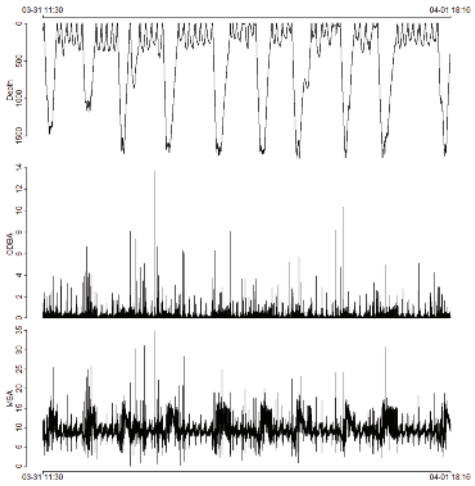
The OE approach involves tagging animals in areas where Navy activities occur; the tags then collect data on how the animals behave when exposed to activities that happen to take place near the animal. This allows animal behavioral data to be collected without needing to schedule with the Navy platforms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

> The resulting comprehensive data set will help to identify and predict the likelihood of a behavioral change as a function of sonar use.

This project is closely coordinated with another LMR-funded project, *Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar* (Project 30, Page 54). That project focuses on coordinated sonar exposure experiments.

The project continued using the Lander2 tag as its primary tag during 2018. This tag includes Fastloc Global Positioning System (GPS) and a 3-axis accelerometer that provide detailed location and movement data. The tags also include high-resolution depth and temperature sensors and a release device within a more hydrodynamic package that is expected to remain attached for longer (and more predictable) time periods. The team will incorporate acoustic recording capabilities to the tag in 2019.

During 2018, the project team completed five field efforts in Southern California, with effort focused on the Southern California Anti-Submarine Warfare



30 hours of baseline dive data collected from one of the tagged beaked whales. The top graph is depth, and the bottom two graphs are representations of animal movement (Overall Dynamic Body Acceleration [ODBA] and Minimum Specific Acceleration {MSA]) collected by the 3-axis accelerometry sensor included in the tag.

Range. Over the course of these field efforts, the team successfully deployed three integrated, medium-term archival tags on Cuvier's beaked whales. Two of the tag deployments on Cuvier's beaked whales stayed attached for longer periods than past deployments, with one attached for six days and the other for 19 days. These provided the longest continuous, high-resolution dive data from Cuvier's that has ever been collected. The tags successfully collected data of both opportunistic and coordinated exposure.

As in the 2017 field efforts, the M3R real-time acoustic detections provided crucial help by directing the tagging boat to target species.

The team is beginning initial data analyses to combine animal movements and diving behavior from tags, tracks from ships and helicopters participating in exercises, and archived acoustic data from the range hydrophones and/or acoustic recording tags in a unified framework. The bulk of these analyses and risk function development will be conducted over the next two years. The resulting comprehensive data set will help to identify and predict the likelihood of a behavioral change as a function of sonar use, including variables such as sonar type, received level (recorded on animal or estimated), distance and orientation of the transmitting vessel, and duration, pattern or frequency of exposure.

This project is working to generate significantly larger samples of high-resolution behavioral data, including accurate movements surrounding real MFAS exposure, particularly for beaked whales. Large sample sizes over broad temporal and spatial scales around real exercises will yield results that are directly applicable to risk function development for Navy compliance efforts. Methods using these tags will be readily transferrable to other species and geographic regions where the Navy needs similar data to estimate the effects of its activities.

About the Principal Investigators

Greg Schorr, a research biologist at the Foundation for Marine Ecology & Telemetry Research, has been studying marine mammals for 20 years. His most recent focus has been using remotely deployed satellite tags to study beaked whale ecology and behavioral responses to anthropogenic sources of sound.

Erin Falcone, a research biologist at the Foundation for Marine Ecology & Telemetry Research, is proficient in all aspects of cetacean satellite telemetry, and deployment of suction cup-attached archival tags. Erin has been co-principal investigator on marine mammal studies at the Southern California Offshore Range since 2006.

Key collaborators include Dave Moretti, Stephanie Watwood and the entire M3R team from the Naval Undersea Warfare Center; Stacy DeRuiter from Calvin College; and Brenda Rone, Russ Andrews, and Alex Zerbini from the Foundation for Marine Ecology & Telemetry Research.

Frequency-dependent Growth and Recovery of TTS in Bottlenose Dolphins

Principal Investigator: Jim Finneran
Project Status: Ongoing, Project 24

NEED

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

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

PROJECT

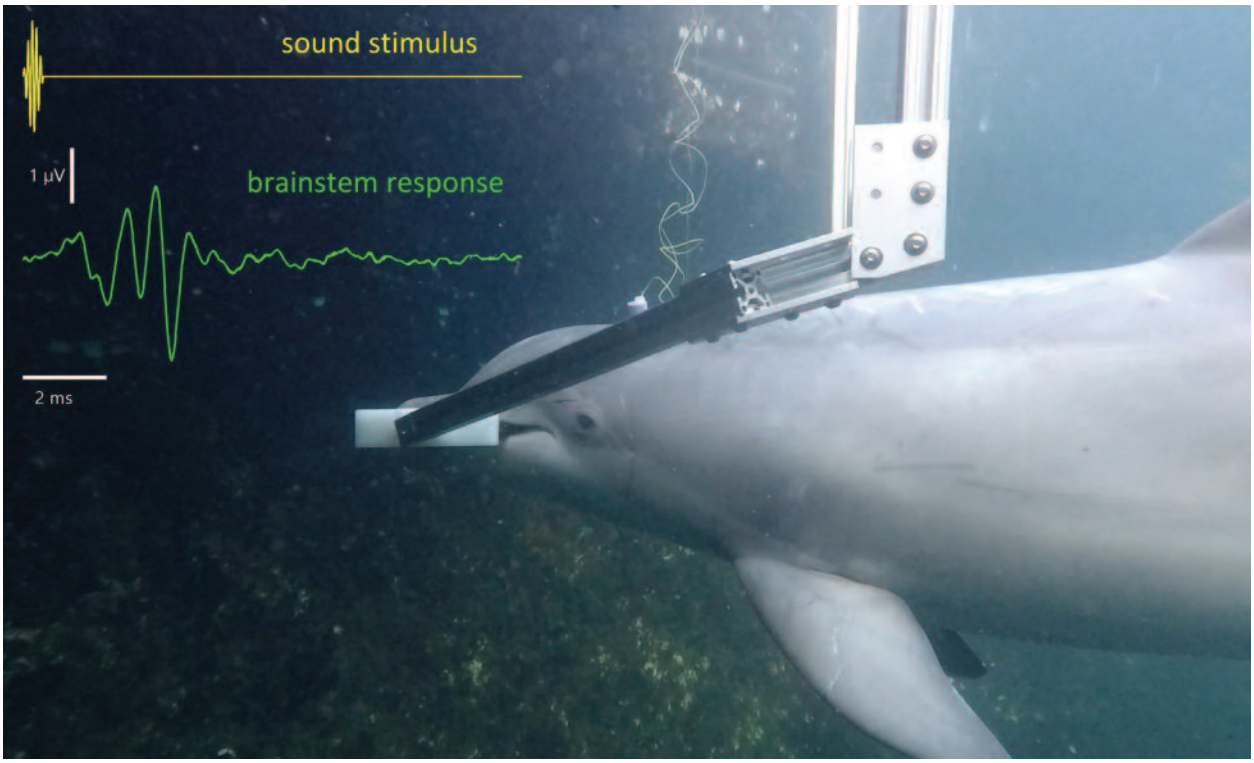
Navy acoustic impact assessments apply auditory weighting functions, similar to those used in assessing risk to human hearing, to predict the occurrence of temporary threshold shift (TTS) and permanent threshold shift (PTS) as functions of frequency. Threshold shift is one of the few direct measures of adverse effects of intense sound on hearing. The associated weighting functions are mathematical functions that emphasize, or "weight," noise at different frequencies according to the listener's susceptibility to noise at that frequency. Direct measurements of TTS in representative marine mammal species—across a broad spectrum of sound frequencies—are needed to support the TTS/PTS thresholds and weighting function derivations.

The objectives of this effort are to: 1) determine exposure levels corresponding to the onset of TTS across a broad range of frequencies in bottlenose dolphins (*Tursiops truncatus*) with full hearing bandwidth (up to frequencies of about 140 to 160 kHz); 2) develop TTS recovery models for use in acoustic impact assessments; and 3) examine the relationship between TTS measured using behavioral methods and auditory evoked potential (AEP) methods.

This information is directly applicable to all Navy environmental compliance documents analyzing potential impacts from acoustic sound sources.

The methodology includes measuring the hearing thresholds in bottlenose dolphins using both behavioral audiometric methods and electrophysiological AEP methods. Researchers establish baseline hearing thresholds, then measure hearing thresholds immediately before and after exposure to a fatiguing noise to determine any threshold shift occurrences. Subject health, welfare and behavior are continuously monitored and managed by attending veterinarians and animal care staff at the Space and Naval Warfare Systems Center Pacific.

Previous year's efforts focused on animal training, baseline hearing measurements and refining the TTS exposure protocols for this study. A key focus during 2018 was collecting high-frequency TTS data. The team completed TTS testing with 80-kHz fatiguing noise with a single dolphin, including 54 control sessions and 21 one-hour exposure sessions at exposure levels of



A U.S. Navy dolphin wears non-invasive, surface electrodes while positioned on an underwater "bite plate" during an auditory brainstem response hearing test. The inset graphs show the time waveforms for the sound stimulus and the averaged brainstem response. Hearing is assessed by varying the sound level and tracking changes to the brainstem response.

SSC Pacific (Distribution A)

approximately 139 to 165 dB SPL, equivalent to approximately 175 to 201 dB sound exposure level (SEL). Results are being analyzed for reporting. The project team also initiated TTS testing with 40-kHz fatiguing noise during 2018, which will continue into 2019. Low- and mid-frequency data collection is planned to begin during 2020.

The data resulting from this effort will be used to update the weighting function and TTS/PTS threshold values for the mid-frequency cetacean group, validate the extrapolation procedures used to derive weighting functions and TTS/PTS thresholds for other species groups, develop practical models for recovery from TTS, and enable broad comparisons between behavioral- and AEP-based measures of TTS. This information is directly applicable to all Navy environmental compliance documents analyzing potential impacts from acoustic sound sources.

About the Principal Investigator

James Finneran has worked as a research scientist at the Space and Naval Warfare Systems Center (SPAWAR) Pacific since 2002, investigating marine mammal echolocation and marine animal auditory capabilities and studying the physiological effects of sound on marine animals. He has a Ph.D. in Mechanical Engineering from The Ohio State University.

A Blainville's Beaked Whale Behavioral Risk Function for Hawaiian Populations

Principal Investigators:
Dave Moretti, Len Thomas, and Elizabeth Henderson
Project Status: Ongoing, Project 25

NEED

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

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

PROJECT

Currently, the Navy's acoustic impact assessments use a behavioral risk function for beaked whales that incorporates a risk function developed for Blainville's beaked whales found at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. The primary goal of this effort is to publish the first behavioral risk function for Blainville's beaked whales (*Mesoplodon densirostris*) found on the Pacific Missile Range Facility (PMRF) undersea hydrophone range in Hawaii. It will provide a direct comparison of risk functions derived for the same species, exposed to the same source types, in different ocean basins. The project is adapting the methods used at AUTEC to animals detected at PMRF and demonstrating how the methodology can be used in different locations.

A number of differences between the AUTEC and PMRF undersea hydrophone ranges require adjustments to the original approach used to develop behavioral risk functions for Blainville's beaked whales at AUTEC. Lower animal densities and more variable hydrophone spacing at PMRF are just two of differences to be accounted for within the modeling.

> The behavioral risk function developed under this project will be based on real Navy sonar source data over a broad scale.

Work during 2018 included completing the hydrophone calibration function that was started in 2017 and fitting data to the existing model to identify needed adjustments. For the initial model fitting, data from SPAWAR recordings were used. These data included marine mammal vocalizations and sonar recorded during three previously conducted PMRF Submarine Command Course (SCC) training events. The received levels at every hydrophone every thirty minutes were modeled using a parabolic propagation model. Blainville's beaked whale dive starts were also detected and assigned to a primary hydrophone. A model was fit to describe the spatial distribution of Blainville's beaked whale dive starts before and during SCC exercises. The model used ship presence and sonar presence (Figure 1) and sound intensity as predictors of Blainville's beaked whale dive starts. Concurrent

with initial fit analyses, the team continued to extract sonar and vocalization data from other SCC events to generate a longer-term data set. Beaked whale and sonar detections were also extracted as M3R data products for all of 2017, in order to look at potential impacts of shorter sonar events on beaked whale dives.

The behavioral risk function developed under this project will be based on real Navy sonar source data over a broad scale and will include a large number (more than 100) of beaked whale dive starts from multiple groups to provide insight into levels at which these animals react in the Hawaii environment.

Project 25 illustration/graph

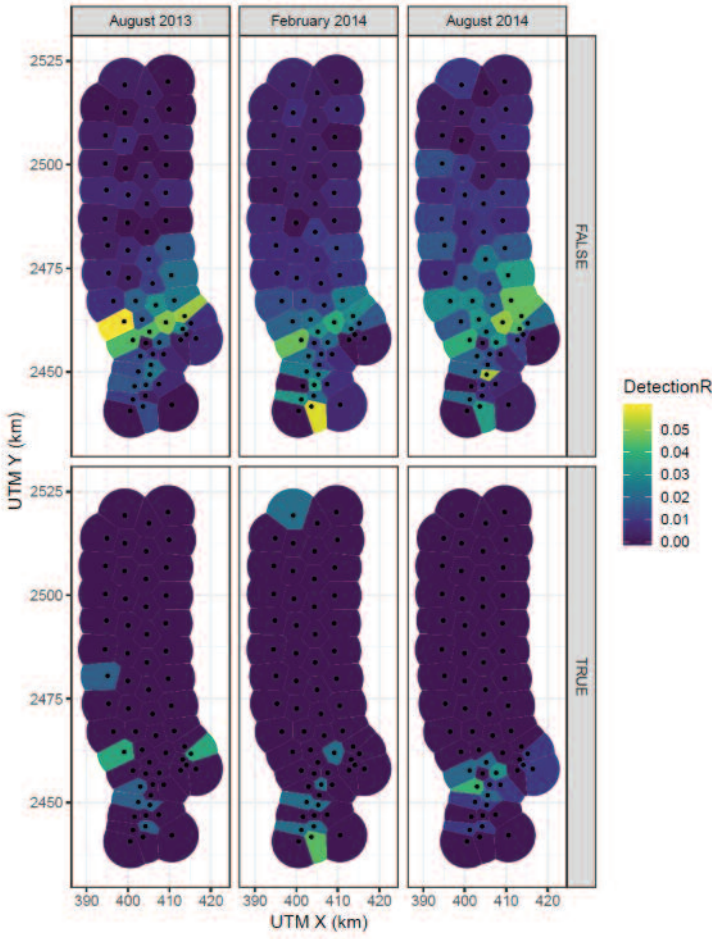
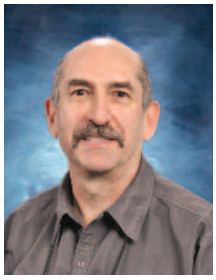


Illustration of the spatial pattern of Blainville's beaked whale acoustic detections without sonar (top panels) and with sonar (bottom panels) on the PMRF range hydrophones during three experimental periods (the three columns). Fewer beaked whale dives are detected during sonar.

About the Principal Investigators

David Moretti is the principal investigator for the Naval Undersea Warfare Center's Marine Mammal Monitoring Program. Dave has 30 years of experience in acoustic signal processing and directs a diverse team of engineers and scientists as part of the Navy's effort to develop and apply passive acoustic signal processing tools to the study of the effect of anthropogenic disturbance, including MFAS, on marine mammals and developing related long-term monitoring algorithms and systems.



Len Thomas, the current director of the University of St Andrews Centre for Research into Ecological and Environmental Modeling (CREEM), specializes in developing statistical methods to apply to ecological problems, including for analysis of behavioral response specifically for Blainville's beaked whales at AUTEC. Dr. Thomas has a Ph.D. in Forestry from the University of British Columbia.

Elizabeth Henderson is a bioacoustic scientist with the Navy Marine Mammal program at the Space and Naval Warfare Systems Center. Dr. Henderson earned her Ph.D. in Marine Biology and Biological Oceanography at the University of California, San Diego. She focuses on bioacoustic and noise impact analyses for environmental compliance.

The Effects of Underwater Explosions on Fish

Principal Investigators:
Peter Dahl and Keith Jenkins
Project Status: Ongoing, Project 26

NEED

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

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

PROJECT

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

The project team is studying explosive effects on fish species with differing characteristics (e.g., different relationship between pressure detector and the ear) and size, at varied water depths and distances from the source. Tissues from exposed fish (as well as from an extensive set of control samples) are examined using quantified necropsy techniques. Careful attention has been focused on ensuring a bio-statically valid design and sample size. This approach will provide a broader and more comprehensive understanding of potential effects and dose-response relationships.

The previous year's efforts focused on drafting the experimental design, building the fish cages, initial field testing, and coordination with the relevant Navy commands. During 2018 the team completed experimental and biostatical planning, obtained the required approval from the Institutional Animal Care and Use Committee (IACUC) and sourced Pacific sardines from the National Marine Fisheries' Southwest Fisheries Science Center. With critical support provided by Navy Explosive Ordnance Disposal technicians, the team conducted both a valuable pilot study and successful Phase I trials.

The Phase I trials, conducted during October, included four events over two weeks. Cages holding Pacific sardines were deployed at 10 meters depth at multiple distances from the explosive source. Cages were immediately raised, survival and external effects were documented, and the fish were prepared for necropsy (animal autopsy) to evaluate internal effects. An important component to the statistical design was including control fish (not exposed to explosive forces) in the

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

Fish cages deployed off of San Diego.
Keith Jenkins

study. The fish were presented for analyses in a manner to ensure that investigators did not know if they were analyzing exposed or control animals. In addition to fish necropsy analyses, the team collected critical data on acoustic explosive energy at the fish cages and along multiple pathways.

Phase I analyses and Phase II trials will be conducted during 2019. The Phase II trials will collect data on another type of fish, potentially one with different swim bladder morphology than the sardines used in 2018. A number of procedural lessons-learned—including sourcing and maintaining target species and ear tissue preservation and analysis techniques—will smooth the way for the 2019 trials.

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

About the Principal Investigators

Peter Dahl is a senior principal engineer in the acoustics department and a professor in the University of Washington's Department of Mechanical Engineering. Dahl's research is in areas of acoustics with primary focus on underwater sound. Dr. Dahl earned his Ph.D. from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1989.

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

Art Popper from the University of Maryland is a key collaborator.

3S3: Behavioral Responses of Cetaceans to Naval Sonar

Principal Investigators:
Frans-Peter Lam and Petter Kvadsheim
Project Status: Ongoing, Project 29

NEED

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

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

PROJECT

Several factors that can influence behavioral response to sonar include sonar sources, sonar types, duty cycle (the ratio of transmission time to repetition time), and the effect of distance between sources and animals. This project is evaluating the potential effects of a relatively new type of sonar—continuously active sonar (CAS) source—as well as several of the other influencing factors.

The 3S (Sea mammals, Sonar, Safety) project is part of a broader international research consortium that has been conducting behavioral response studies on six different cetacean species in North Atlantic waters since 2006. The current (third) phase of the 3S project (3S3) is evaluating whether exposure to CAS leads to different types or severity of behavioral responses than exposure to traditional intermittent pulsed active sonar (PAS) signals. The project also is evaluating how the distance between the source and animals affects behavioral responses.

The project is being funded in partnership with the LMR program and the United Kingdom, French, Norwegian and Dutch naval authorities. Coordinating with this international effort will help both the U.S. Navy and allies in the North Atlantic Treaty Organization (NATO).

> Data on how marine mammals respond to CAS and PAS, in addition to distance from the source, will continue to improve the impact assessment of behavioral response.

This phase of the 3S project is focused on addressing two separate questions in parallel using the same experimental design:

1. Does exposure to CAS lead to different types or severity of behavioral responses than exposure to traditional PAS signals, or does the CAS feature of high duty cycle lead to acoustic responses that indicate masking?
2. How does the distance to the source affect behavioral responses?

Field efforts have been conducted in Norwegian waters along Norway's northern coast. Focus animals have included sperm whales (*Physeter macrocephalus*), pilot whales (*Globicephala melas*) and killer whales (*Orcinus orca*).

The project has employed controlled (sonar) exposure experiments (CEE). The research team uses visual observers and acoustic arrays to locate whales of interest. When animals are located, a digital acoustic monitoring tag (DTAG)—in this case DTAG3 or a mixed-DTAG—is attached by non-invasive suction cups to each animal that can be approached. The sensor package of the mixed-DTAG adds a GPS logger and satellite transmitter to the DTAG3 sensor package. The tags are programmed to release after 15-17 hours.

After establishing baseline behavior characteristics of each tagged whale, and ensuring all protection measures are in place, the team initiates the experimental phase, the CEE. Each tagged subject is exposed to both CAS and PAS as well as a no-sonar control experiment. Well established analytical approaches to contrast the effects of range and CAS versus PAS will be employed during data analysis.

During the 2017 field season, the team successfully deployed DTAG3s or mixed-DTAGs on 11 sperm whales and two pilot whales to record vocal, movement and dive behavior. Fifty-six hours of baseline behavioral data were collected on sperm whales and seven sonar CEEs were conducted with a scaled (but still realistic) sonar source. Baseline data also were collected from pilot whales.

Whenever possible, photos are collected for photographic identification of animals. For pilot whales, images of the dorsal fins allow researchers to tell individuals apart and can help determine if these animals have been sighted before.

Rune Roland Hansen, Norwegian Animal Research Authority (Mattilsynet) permit 2015/223222

During 2018, the team focused on analyzing data collected during 2017 and on further testing of the mixed-DTAGs. Initial results from the 2017 field season suggest that for sperm whales, responses to CAS and PAS are statistically indistinguishable when Sound Exposure Level (SEL) is the same. A manuscript detailing these results is in preparation. The mixed-DTAG was tested with GPS and ARGOS Goniometer components to resolve problems that occurred during the 2017 field season. In addition, the team evaluated a preferred tracking configuration and additional refinements that were needed. The mixed-DTAG is now ready for the 2019 field season.

The 2019 efforts will include working with a Norwegian Navy frigate. The goal is to collect data on received levels from an actual operational source transmitting at varying levels and distances. In addition to collecting exposure to range data with the Norwegian frigate, project plans for 2019 include CAS vs PAS experiments with pilot or killer whales using a scaled sonar source.

Data on how marine mammals respond to CAS and PAS, in addition to distance from the source, will continue to improve the impact assessment of behavioral response. The direct data on actual behavioral responses in controlled conditions with free-ranging

The tags attach to the whale using minimally invasive suction cups, which stick to the whale for up to 24 hours.
After tagging, the whale is tracked visually and acoustically, and using VHF signals given off by the tag itself when at the surface.
Lucia Martin, Norwegian Animal Research Authority (Mattilsynet) permit 2015/223222

cetaceans will allow the Navy to better estimate the potential effects of sonar use on marine mammals.

About the Principal Investigators

Frans-Peter Lam, the lead principal investigator (PI), is a senior scientist at The Netherlands Organization for Applied Scientific Research. 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.

Petter Kvadsheim, co-PI, is a principal scientist and program manager with FFI (Norwegian Defence Research Establishment). Dr. Kvadsheim earned his Ph.D. in Zoophysiology from the University of Tromsø, Norway.

Patrick Miller, co-PI, is a senior research fellow at the Sea Mammal Research Unit and professor in the School of Biology, University of St Andrews, Scotland. Professor Miller earned his Ph.D. in Biological Oceanography from the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology joint program.

A group of about 50 orca feeding near the R/V H.U. Sverdrup II at 2:00am. During the midnight sun it is possible to observe whales for 24 hours a day.
Paul Wensveen, Norwegian Animal Research Authority (Mattilsynet) permit 2015/223222

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

Principal Investigator: Stephanie Watwood
Project Status: Ongoing, Project 30

NEED

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

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

PROJECT

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

This project is conducting coordinated sonar exposure experiments (CSEE) using sonar from two different platforms, each of which will be deployed at multiple, pre-defined distances from tagged animals. The effort is closely coordinated with another LMR-funded project that is using high-resolution, medium-duration monitoring tags to record behavioral responses of Cuvier's beaked whales and fin whales during Navy training and testing activities. That project (Project 23, page 42), is employing an opportunistic exposure (OE) approach, in which animals are tagged prior to Navy training activities in order to document the behavior of animals before, during and after the actual Navy exercises. The data from the CSEEs will augment the OE data.

> The results will allow the Navy to…better estimate the potential effects of sonar use on Cuvier's beaked whales and fin whales within the Southern California ranges.

The CSEE project includes both exposure and control scenarios for each of two types of sonar platforms—helicopter-dipping sonar and directional command activated sonobuoy system (DICASS) sonobuoys. These were selected based on how frequently they are used during training on the Southern California Antisubmarine Warfare Range. Each sonar type is being tested as outlined in the above table. Standard mitigation actions are conducted prior to all experiments, as outlined in the research permits.

The tagging team from Project 23 deploys the high-resolution, behavior recording tags deployed on whales on the Southern California Offshore Range (SCORE) to collect animal response data. The two species of particular interest are Cuvier's beaked whales (*Ziphius cavirostris*) and ESA-listed fin whales (*Balaenoptera physalus*). After animals are successfully tagged, the team coordinates with the helicopter crews that work with dipping

	HELICOPTER-DIPPING SONAR	DICASS SONOBUOYS FROM TAGGING BOAT
Transmission (exposure)	Helicopter conducts dipping sonar at typical depth and source level at defined distances from tagged animal (generally beginning distant then progressively closer).	Tagging boat (rigid hulled inflatable boat or RHIB) arrives at the farthest defined distance; team deploys sonobuoy over the side to standard depth, and sonar is transmitted at a defined time. This is repeated at different and progressively closer distances.
No transmission (control)	Helicopter conducts dipping sonar maneuvers at typical depth but does not transmit. Conducted at the same defined distances as exposure.	RHIB team deploys sonobuoy over the side to standard depth, no sonar transmitted. Repeated at each of the defined distances as exposure.

sonar. Using tag location data, the team calculates a proposed dipping location for the helicopter crew.

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

As with the OE project, data from this project will be analyzed within a unified framework that combines whale movements and diving behavior from tags, tracks from platforms participating in the experiments and archived acoustic data from the range hydrophones and/or acoustic recording tags. Combining these pieces will help to predict the likelihood of a behavioral change as a function of sonar use, including variables such as sonar type, received level (recorded on animal or estimated), distance and orientation of the transmitting platform, and the sonar exposure characteristics.


A breaching juvenile Blainville's beaked whale.
Mark Deakos, permit 14451

Adding this CSEE effort to the ongoing OE project will generate larger samples of high-resolution behavioral data, including both transmission and non-transmission control experiments in predictable patterns at multiple, predetermined distances. This approach enhances assessment of range to effect on behavioral response and continues development of the CSEE methodology through the use of the two source types, helicopter dipping sonar and sonobuoys.

The results will allow the Navy to improve impact assessments and better estimate the potential effects of sonar use on Cuvier's beaked whales and fin whales within the Southern California ranges.

About the Principal Investigator

Stephanie Watwood is a biologist at the Naval Undersea Warfare Center (NUWC). She has extensive experience in collecting and analyzing cetacean acoustic data, particularly related to cetacean behavior. Dr. Watwood holds a Ph.D. in Biological Oceanography from the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology joint program.

Key collaborators include Dave Moretti from NUWC; Greg Schorr, Erin Falcone and Brenda Rone from the Foundation for Marine Ecology & Telemetry Research (MarCoTel); Alex Zerbini from MarCoTel and NOAA; and Stacy DeRuiter from Calvin College.

Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

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

NEED

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

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

PROJECT

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

This project is obtaining reliable measures of auditory sensitivity—across the full frequency range of hearing—for a specially trained adult male Hawaiian monk seal. The resulting data will be used to generate both underwater and in-air audiograms that will help to support impact assessments of the Hawaiian monk seal's hearing range and sensitivity to sound. The project also is recording audio and video of underwater sound production to provide previously unavailable descriptions of underwater sounds produced by male monk seals.

Researchers are working with an adult male Hawaiian monk seal currently in residence at the University of California at Santa Cruz's Long Marine Laboratory. The seal was previously trained for cooperative physiological research and is now participating in hearing tests in the laboratory.

> The results will…allow the Navy to…better estimate the potential acoustic effects on monk seals resulting from Navy training and testing activities.

Experimental conditions are carefully controlled to minimize potential effects of unintended environmental sounds or behavioral cueing. Testing methodology is an established behavioral psychoacoustic approach (a go/no-go choice procedure) to measure the minimum sound levels reliably detected by the seal at a range of frequencies in water and in air. Underwater testing is conducted in an acoustically calibrated pool. In-air testing is conducted nearby in a hemi-anechoic (echo-dampening) room custom-built for measuring hearing in large animals. The resulting hearing profiles, or audiograms, will provide reliable information about the monk seal's ability to detect and respond to sounds that may be present in natural environments.

Work during 2018 centered on testing underwater hearing and providing an initial description of underwater sound production for the species. Before actual hearing tests the researchers characterized all ambient noise, mapped the acoustic sound field, calibrated the test stimuli and completed training within the testing enclosure. They then measured underwater auditory thresholds across the frequency range of hearing. The test signals were narrow-band 500 millisecond frequency-modulated sweeps at fourteen frequencies from 0.1 to 60.9 kHz.

Underwater hearing test results revealed that Hawaiian monk seals hear better at lower frequencies than previously believed. The hearing range is generally consistent with other seals at lower frequencies. Best hearing appears to fall within a range of approximately 0.3 to 30 kHz. The high frequency roll-off is consistent with an early report concerning hearing in Hawaiian monk seals but occurs at lower frequencies than has been reported for other phocid seals (true seals).

Sound production measurement efforts during 2018 included year-round sound recordings validated by video data that are used to describe call repertoire and to determine seasonal patterns in vocal behavior. Results include spectrograms of underwater vocalizations, which are visually and aurally examined to detect and perceptually classify underwater vocalizations. High-quality calls are then extracted for statistical analyses. While data collection is ongoing, initial results suggest at least six underwater call types for this species, that was previously believed to be silent in water. The calling frequency spectrum appears to overlap with the seal's best underwater hearing range. Additionally, vocalizations appear to track a prolonged annual reproductive season.

Project efforts during 2019 will focus on completing underwater sound production measurements and conducting in-air hearing measurements.

Hawaiian monk seal.
Colleen Reichmuth, permit NMFS 19590-02

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

About the Principal Investigators

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

Dr. Jillian Sills is a postdoctoral scholar at the University of California at Santa Cruz. She is a skilled bioacoustican that has conducted auditory research with harbor seals, spotted seals, ringed seals, bearded seals, sea lions and sea otters.

New Start Project

TTS in Harbor Seals Due to Fatiguing Sound of Several Frequencies

Principal Investigator: Ron Kastelein
Project Status: New start, Project 33

NEED

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

The Navy needs additional 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 (hearing sensitivity) in marine species, data on temporary threshold shift (TTS) due to various frequencies, and effects on fish due to 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 focuses on TTS and hearing recovery in harbor seals for deriving auditory weighting functions for seals. Harbor seals are appropriate subjects for multiple reasons. They have a wide distribution in the northern hemisphere and sometimes overlap with areas used for U.S. Navy training and testing activities. With their acute underwater hearing, sounds from the training and testing activities are audible to harbor seals. In addition, while susceptibility to TTS has been shown to be frequency-dependent in bottlenose dolphins (*Tursiops truncatus*) and harbor porpoises (*Phocoena phocoena*), currently it is not clear how sounds of different frequencies may affect the hearing of harbor seals across their entire functional hearing range.

The resulting data will be used to define the hearing weighting function and TTS/PTS threshold values for the phocid (seals) group.

To evaluate the frequency-dependence in seal hearing, the project goals are to

1. Determine the susceptibility to TTS of harbor seals over their entire hearing range
2. Determine TTS onset, relationship between sound exposure level (SEL, a unit which contains both the exposure level and the exposure duration) and TTS after the harbor seals have been exposed to sounds of various frequencies. Because all exposures in this study will be 1 hour, the reported SELs are 36 decibels higher than the reported sound pressure levels (SPL)

Female seal 01 hauled out (showing dry hair). During fatiguing sound distribution measurements (for the TTS study) in the pool, the animals are kept on land and thus their hair dries.
Ron Kastelein, SEAMARCO

Trainer applying zinc ointment on the head of seal 02 to enable individual recognition of the two seals during the sound exposure, to calculate the distances between the seals and the sound source (for the exposure periods of the temporary hearing threshold shift (TTS) study).
Ron Kastelein, SEAMARCO

3. Determine which hearing frequency is most affected by each fatiguing sound frequency
4. Determine the recovery rate of hearing after the fatiguing sound stops
5. Based on the information derived for goals 1-3, construct equal-TTS curves (one of which will be the TTS onset curve).

Results from these tests on harbor seals will be used as the model for all true seals (phocids).

The project is employing two harbor seals that have been trained for research and have participated almost daily in psychophysical acoustic research for 14 years. During a hearing test, the trained harbor seals will wait at a listening station, at a specific distance from the underwater loudspeaker. When they hear a sound, they will leave the station and swim towards the trainer for a reward. Each TTS session will include a pre-exposure hearing test, exposure to a fatiguing sound of a particular frequency and several post-exposure hearing threshold measurements to determine the rate of recovery of hearing.

Nine fatiguing sounds are being tested: a continuous tone (6.5 kilohertz or kHz) and continuous 1/6-octave noise bands centered at 0.125, 0.250, 0.5, 1.0, 2.0, 16, 32 and 40 kHz. Control sessions are conducted for each hearing test frequency. Exposure duration will be one hour per session. Each fatiguing sound will be produced at five SPLs, of which three will result in approximately the following TTS levels: 6, 12 and 18 decibels. This approach provides insight into the relationship between TTS and SPL. Two or three hearing frequencies will be tested per fatiguing sound frequency (often the highest TTS occurs at a higher frequency than the frequency of the fatiguing sound). Each of the three highest SPLs (and the controls) will be replicated multiple times.

The resulting data will be used to define the Navy Phase IV hearing weighting function and TTS/PTS threshold values for the phocid (seals) group. The data will be directly applicable to all Navy environmental documents analyzing acoustic effects of tonal sounds (e.g., sonars) and broadband noise sources.

About the Principal Investigator

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

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 ability to collect, process, exploit and disseminate vast amounts of information is key to continually advancing the Navy's undersea capabilities.

The following section includes summaries of four projects—three ongoing projects and one new project started in 2018.

Ongoing

1. Project 17 Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data
2. Project 19 DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas
3. Project 31 DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling

New start

1. Project 36 Analytical Methods to Support Development of Noise Exposure Criteria for Behavioral Response

Fin whale.
Jeff Foster, NMFS permit 16111

Ongoing Projects

Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data

Principal Investigator: Ana Širović
Project Status: Ongoing, Project 17

NEED

N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data

The Navy needs to be able to derive improved density estimates for species of concern using Passive Acoustic Monitoring (PAM) data collected at sites of high Navy interest. Density estimation from PAM data requires a high level of data collection planning, metadata collection and external calibration of detection rates. The Navy needs a methodology that would include planning of a survey, collection of data and development of analyzed density data products that can be incorporated into the Navy Marine Species Density Data (MSDD) archive.

PROJECT

This main goal of this project is to develop spatially and temporally explicit density estimates, using passive acoustic data, for blue and fin whales in the Southern California (SOCAL) range to provide data necessary for the Navy's acoustic impact assessments.

To estimate density from passive acoustic data, it is necessary to know the animals' average call rates, the call detection range and the probability of call detection within that range. The project is leveraging results from work completed under ONR funding, using long-term passive acoustic data sets from SOCAL and using acoustic tag data from the SOCAL Behavioral Response Study and other tagging studies in the area. In addition, this project will include deployment of newly available long-term tags. The long-term tag data provide more information on variations between night and day behaviors influencing calls.

Call detection ranges and probability of call detection entail acoustic propagation models. Parameters that affect propagation include bathymetry and sediment layer. Thicker sediment influences the loss of sound over distance, which needs to be assessed within detection range estimates.

The goal of this project is to develop explicit density estimates for blue and fin whales…for the Navy's acoustic impact assessments.

Work during 2017 focused on conducting field surveys to collect new data and beginning to analyze call rates for blue whales.

During 2018, the project team worked both on blue whale call modeling and on additional field efforts. Efforts included transitioning acoustic propagation and probability of detection models for blue whale calls from a previously completed LMR project (Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals, Tyler Helble) into this project. The team also developed models for blue whale D call cue rates that can be applied to time series of acoustic detections. This included defining uncertainty estimates at each step of the process, which are critical for understanding total uncertainty in final density estimates.

Field efforts in 2018 focused on tagging fin whales to collect call data. Field teams deployed tags on five fin whales, capturing almost 390 hours of data and substantially increasing the number of acoustics calls recorded on tags from fin whales. Calling behavior data from these tags are being analyzed and integrated with previous fin whale tag data to develop models of fin whale acoustic behavior.

Work in 2019 will focus on finalizing density estimates for blue whales at multiple SOCAL sites, as well as development of the fin whale automatic call detection process to apply density estimation methodologies developed for blue whales to that species as well.

About the Principal Investigator

Ana Širović is an associate professor in the Department of Marine Biology at Texas A&M University Galveston. Her research focus is on marine bioacoustics of highly exploited and endangered marine mammal and fish species, and on effects of anthropogenic noise in the ocean. Dr. Širović earned her Ph.D. in Oceanography from the University of California San Diego.

Key collaborators include John Calambokidis, Cascadia Research Collective; Goldie Phillips, Scripps Institution of Oceanography; Tyler Helble, Space and Naval Warfare Systems Center.

Tagging team approaching a blue whale.
Tom Greene, permits 16111 and 19116

DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas

Principal Investigators:
Len Thomas and Dave Moretti
Project Status: Ongoing, Project 19

NEED

N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data

The Navy needs to be able to derive improved density estimates for species of concern using Passive Acoustic Monitoring (PAM) data collected at sites of high Navy interest. Density estimation from PAM data requires a high level of data collection planning, metadata collection and external calibration of detection rates. The Navy needs a methodology that would include planning of a survey, collection of data and development of analyzed density data products that can be incorporated into the Navy Marine Species Density Data (MSDD) archive.

PROJECT

This project is working to demonstrate and validate a method for monitoring animal density using only passive acoustic recordings. The project plans to collect data from retrievable, bottom-mounted passive acoustic sensor arrays adjacent to or overlapping the Southern California Anti-Submarine Warfare Range. Data from these sensors, in conjunction with estimates of vocalization rates from existing and ongoing studies (e.g., LMR project 17, page 61), then will be used to estimate density values and create animal distribution maps for two case-study species: Cuvier's beaked whale and fin whale. The project is using data from both the Southern California (SOCAL) Behavioral Response Study and the Marine Mammal Monitoring on Ranges (M3R) system—the former to give information about acoustic behavior and the latter to allow validation of findings from the retrievable array.

The design for optimal acoustic recorder array spacing was finalized in 2017, and major progress was made on the hardware design and modification. Work during 2018 centered on field testing the passive acoustic sensor arrays. The system, called a Portable Acoustic Data Node (PADN), was designed and constructed by team members at the Naval Undersea Warfare Center Newport. The PADN system is equipped with four hydrophones that form a tetrahedral array. The four hydrophones in the tetrahedral array provide signal bearing estimates necessary to the statistical density estimates.

> Such capability could be a valuable tool for providing data to the Navy Marine Species Density Data (MSDD) archive.

A field test was completed in Narragansett Bay, Rhode Island. A second system field test was conducted on the Southern California Offshore Range during the summer of 2018. Following successful deployment and initial testing, problems arose during retrieval. The PADN systems are configured to release by an acoustic signal and float to the surface, however none of the three systems released as intended. Following retrieval by a remotely operated vehicle, the systems are being analyzed to identify the release problem to ensure successful release in future efforts.

Another deployment of the PADN systems is planned for 2019. Density estimation algorithms will be tested in 2019 after sufficient data are collected.

Preparing to deploy Portable Acoustic Data Nodes.
Anu Kumar

The intended density estimates for Cuvier's beaked whales and fin whales in SOCAL will support associated animal distribution maps based on data from both instrumented and non-instrumented ranges. Such capability could be a valuable tool for providing data to the Navy Marine Species Density Data (MSDD) archive.

About the Principal Investigators

Len Thomas, the current director of the University of St Andrews Centre for Research into Ecological and Environmental Modeling (CREEM), specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in Forestry from the University of British Columbia.

David Moretti is the principal investigator for the Naval Undersea Warfare Center's Marine Mammal Monitoring Program. Dave has 30 years of experience in acoustic signal processing and directs a diverse team of engineers and scientists as part of the Navy's effort to develop and apply passive acoustic signal processing tools to the study of the effect of anthropogenic disturbance, including MFAS, on marine mammals and developing related long-term monitoring algorithms and systems.

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

Principal Investigator: Len Thomas
Project Status: Ongoing, Project 31

NEED

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

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

PROJECT

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

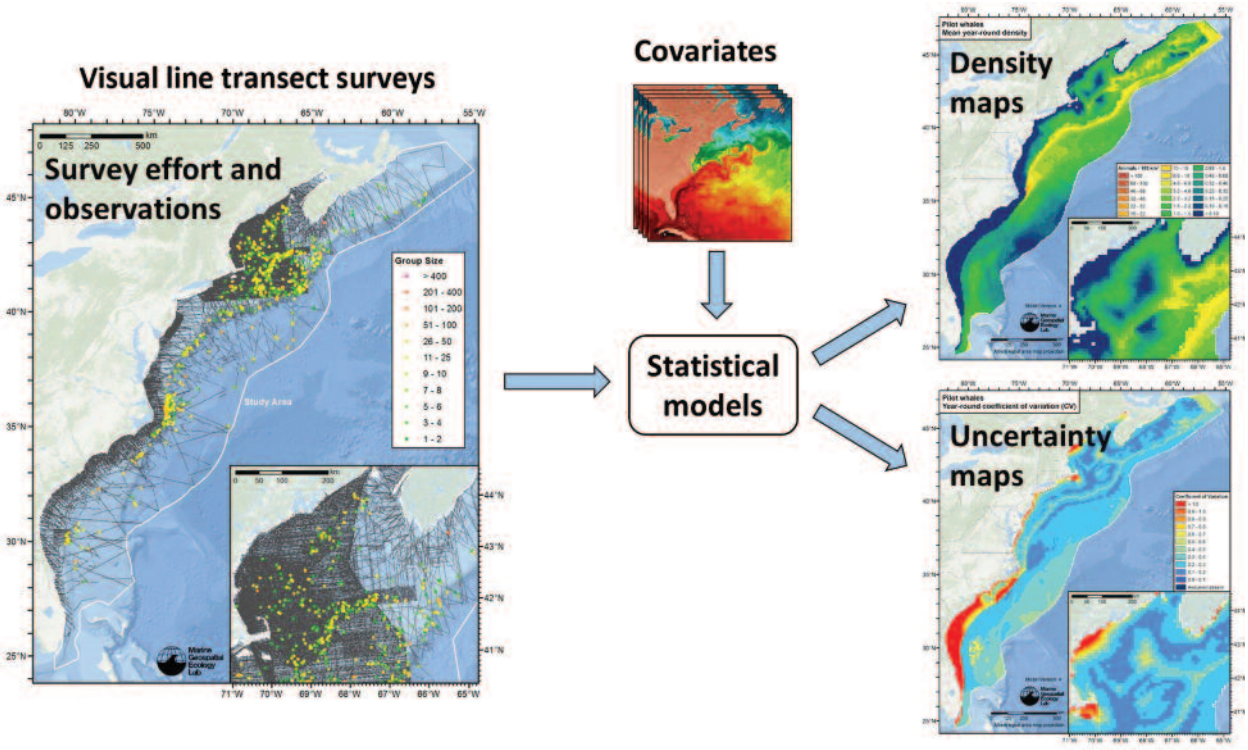
In this project, a working group is focused on developing and implementing innovative approaches to improve spatial modeling methods used to characterize seasonal abundance and distribution of marine species. The participating organizations lead in the development and application of the survey and analysis methods used—

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

the University of St Andrews, Duke University and the four regional NOAA Fisheries labs—and includes the parties largely responsible for collection and analysis of transect data used in Navy impact assessments. Goals include producing software tools that implement new approaches and providing statistical support to those tasked with undertaking density surface modeling for the Navy. The team will develop concrete guidance on best practices in this type of modeling.

Five technical sub-groups are focused on key issues that were identified early in the process. The sub-groups' focus and 2018 progress are summarized below.

1. Uncertainty estimation. There are numerous sources of uncertainty when modeling the spatial distribution of animals that are hard to see (and sometimes submerged) in a dynamic environment. This sub-group focuses on correctly quantifying the effects of these uncertainties on the final uncertainty in maps and abundance estimates. So far, the sub-group has derived a general method to include uncertainty from multi-stage models within the generalized additive modeling framework. A manuscript presenting the method has been submitted for publication and the method is implemented in the R programming language.
2. Extrapolation. The Navy requires density estimates in areas where there are no data. Such extrapolation



In density surface modeling, marine mammal survey data (typically from visual line transect surveys) is combined with spatially referenced explanatory variables ("covariates") such as bathymetry, bottom slope and sea surface temperature using sophisticated statistical models that account for variation in sighting conditions as well as animal density. The models can be used to produce density maps, as well as maps showing uncertainty in the estimates.

Jason Roberts, Duke University

makes assumptions on the correctness of the model used. This sub-group is preparing a guidance document (to be developed into a journal article), along with software, to describe and diagnose extrapolation of different types. The sub-group is also developing new modeling methods that give more reliable density and uncertainty estimates when extrapolating.

3. Model unification. There are a wide variety of different modeling techniques that can be used to obtain spatially-explicit estimates of density, but many of these lead to similar results. This sub-group is looking at the similarities between existing methods to ensure that practitioners are using the best possible methods and not investing time and resources in new methods that lead to little benefit. So far one manuscript has been submitted showing how two popular methods are equivalent.

4. Workflow. A wide variety of data preparation and modeling workflows have evolved over time within the different organizations that provide densities to the Navy. The workflow sub-group aims to encapsulate this information. The sub-group has compiled an internal wiki of frequently asked questions that give best practice, software/literature resources and a forum for discussion for those engaged in modeling. This will ultimately become publicly available.

5. Pinnipeds. Based on input from the project's first public meeting, a sub-group on pinnipeds was formed. Pinnipeds raise unique issues when it comes to abundance estimation, as at-sea data are scarce, but counts from haul-outs and movement data from tags are common. This sub-group is focused on working out how best to use and combine these disparate data.

The project held its second annual meeting in the fourth quarter of 2018. In addition to reviewing efforts by the technical sub-groups, a representative from the Navy Acoustics Effects Model (NAEMO) gave a presentation on the Navy's modeling. There was discussion of how passive acoustic data fits within density surface models from experts outside the group. This resulted in the formation of a technical sub-group with a focus on data from passive acoustics.

This project's outcomes will lead to a substantial improvement in the reliability of the Navy's impact assessments in training and testing areas. The Navy will benefit from this collaborative approach to advancing the density surface modeling methods that are applied in developing population estimates for the Navy impact assessments.

About the Principal Investigator

Len Thomas, the current director of the University of St Andrews Centre for Research into Ecological and Environmental Modeling (CREEM), specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in Forestry from the University of British Columbia.

Key collaborators include David Miller and Catriona Harris from the University of St Andrews and Pat Halpin, Jason Roberts and Rob Schick from Duke University.

Humpback whale.

New Start Project

Analytical Methods to Support Development of Noise Exposure Criteria for Behavioral Response

Principal Investigators:
Len Thomas and Catriona Harris
Project Status: New start, Project 36

NEED

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

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

PROJECT

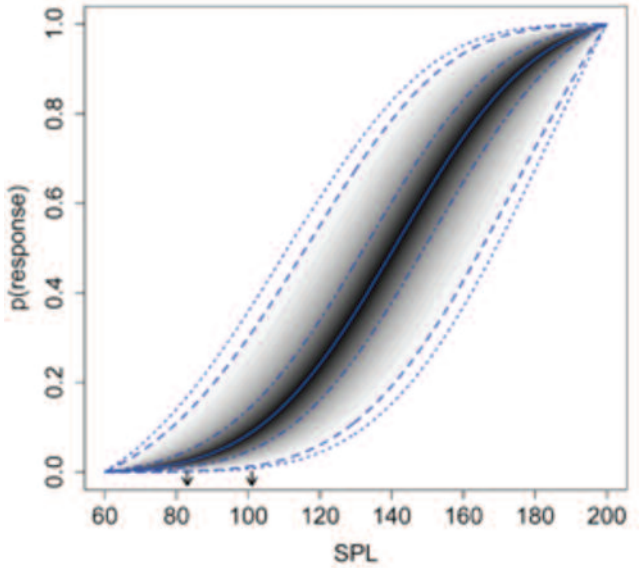
Criteria for estimating effects of anthropogenic sound on marine mammal species currently are established for species groups based on functional hearing characteristics. Results of various behavioral response studies (BRS) suggest that these groupings might not be sufficient for predicting response to sonar. To expand the utility of data collected from BRS and to improve the approach to grouping species for exposure criteria, the Navy needs additional, more efficient modeling methods for estimating responses of multiple species.

This project is focused on developing a computationally efficient model selection method that supports and expands upon the existing Bayesian hierarchical dose-response framework that has been and continues to be employed. The model selection method will seek to enable many more species and covariates (e.g., signal type, whale-source range, received exposure level, animal behavior at time of exposure, etc.) to be included in the model. The overall goal is to develop an objective, data-driven methodology for selecting species groupings, relevant covariates and dose metrics, and appropriate functional forms for the dose response function in support of noise exposure criteria.

The results will offer species groupings for use by those developing the Navy's Phase IV behavioral risk functions.

The project team will build on outcomes of the ONR-funded MOCHA (Multi-study Ocean Acoustics Human Effects Analysis) project (https://synergy. st-andrews. ac. uk/mocha) to develop a new model selection method. Work will include investigating alternative dose-response functional forms (e.g., biphasic functions), evaluating such functions across species and species groups using model selection methods and investigating survival analysis concepts. The methods will be tested using simulated data and multi-species data compiled during the MOCHA project, and newer data. The team will run analyses with a full data set and align outputs with identified requirements from a data workshop.

The project team will aim to derive exposure-response functions for each selected species group. They also will evaluate explicitly how contextual covariates contribute



An example of a Bayesian dose-response function developed during the ONR-funded MOCHA project.
Figure taken from Miller, P.J.O. et al. 2014. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. Journal of the Acoustical Society of America 135: 975-993.

to outcomes. A priority dose metric to investigate will be whale-source range because an important need is to understand the relationship between how the range (distance) of the sound source to the animal may affect behavioral response.

Developing a more efficient model selection method will maximize the potential of the existing Bayesian hierarchical dose-response framework. The results will offer species groupings for use by those developing the Navy's Phase IV behavioral risk functions. While the groupings will not be required to be used, they will, at a minimum, provide another piece of evidence to inform the creation of species groupings. The proposed work will also address the need to understand the relationship between responsiveness and dose metrics other than those related to received sound level. The model will use currently available data both to fit a relationship between whale-source range and probability of response and to determine the form of this relationship and the level of variability within and between species. The outcomes will offer guidance on data requirements, data formats, priority covariates and dose metrics to ensure data collected in the future can be utilized in this framework.

North Atlantic right whale.
Georgia Department of Natural Resources, permit 15488

About the Principal Investigators

Len Thomas, the current director of the University of St Andrews Centre for Research into Ecological and Environmental Modeling (CREEM), specializes in developing statistical methods to apply to ecological problems, including for analysis of behavioral response specifically for Blainville's beaked whales at AUTEC. Dr. Thomas has a Ph.D. in Forestry from the University of British Columbia.

Catriona Harris, a senior research fellow at the University of St Andrews Centre for Research into Ecological and Environmental Modeling (CREEM), has been carrying out research on the impact of anthropogenic noise on marine mammals for 12 years, and specifically behavioral responses of marine mammals to noise, for over seven years. She was co-PI on the MOCHA project which developed analytical methods for analyzing data from behavioral response studies.

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 Marine Species Monitoring Program in support of the Navy's environmental compliance and permitting processes.

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

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

The following two ongoing projects are summarized in this section.

1. Project 21 Extended Duration Acoustic Tagging of Right Whales
2. Project 27 High Fidelity Acoustic and Fine-scale Movement Tags.

These technology investments enable efficient and cost-effective implementation of the Navy's Marine Species Monitoring Program.

MCS3 Ryan M. Breeden

Extended Duration Acoustic Tagging of Right Whales

Principal Investigators:
Susan Parks and Doug Nowacek
Project Status: Ongoing, Project 21

NEED

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

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

PROJECT

The digital acoustic recording tag (DTAG) is one type of tag that can be non-invasively attached to an animal to capture baseline data on sound production for a wide range of critical marine mammal species. As tag technology has improved, these tags offer longer recording times (up to 72 hours), which would provide better insights into the tagged animal's behavior. The non-invasive suction cup attachment mechanisms that are often used with DTAGs, however, generally do not stay attached for long periods, thus limiting data collection to less than one day.

This project is testing new micro-texture suction cups for non-invasive tags on baleen whales to provide the longer sampling times needed to improve animal movement and behavioral response data collection. Glue attachment tests also were planned but have not occurred to date. The testing within this study was the first to apply tags with the newly developed micro-texture suction cups to a free-ranging baleen whale.

The original project plan was to test the attachment of DTAG-3s using micro-textured cups and biocompatible glues during monitoring studies of North Atlantic right whales off the Southeastern United States. The monitoring studies, supported by U.S. Fleet Forces, are focused on right whales due to their endangered status and proximity to the undersea warfare training range off of Jacksonville, Florida. This training range is one of the identified priority regions for the LMR program and the Navy.

Poor tagging conditions during the 2017 monitoring season prevented testing the new tag attachments on right whales. The team subsequently was able to conduct a few tests of suction cups of varying stiffness (all with micro-texture) on humpback whales in the Northeast during summer 2017. Researchers analyzed the

This project is testing new micro-texture and glue attachment methods for non-invasive tags to provide the longer sampling times needed to improve animal movement and behavioral response data collection.

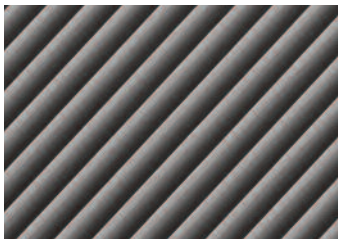
Tagging humpback whales using new suction cups.
J. Tackaberry NMFS ESA/MMPA permit 18059

results of the humpback tagging to identify possible design modifications.

The team selected two versions of the micro-texture suction cups for testing during 2018— Shore 40A cup (standard D3 suction cup material with micro-texture) and a slightly firmer Shore 60A cup. These two suction cup versions were used for tagging during the June 2018 Stellwagen Bank National Marine Sanctuary humpback whale research program's field season. The 2018 field effort included only five days of weather suitable for tagging. The Shore 40A and Shore 60A cups were deployed a total of four times, two times for each cup type. Tag attachment times ranged from 11.5 to 26 hours. Analysis of tag data revealed that all tags detached due either to extended periods of whale breaching or to impacts with other whales and/or the bottom during foraging activities. In attachments with the firmer cup material (Shore 60A) there was evidence of the tag moving or sliding on the animal prior to the high-energy event resulting in detachment. This suggests that the stiffer microtextured cups are not as efficient at resisting shear forces. However, the longest DTAG-3 deployment (26 hours) to date occurred using firmer micro-texture cups.

The team also used the firmer Shore 60A cup while tagging Southern right whales as a part of a Marine Mammal Commission funded field season in Brazil in August 2018. This effort provided three tagging days. Tag attachment times for mother-calf pairs were short, which was anticipated due to the frequent physical interactions between a mother and calf. A deployment on a juvenile whale resulted in 6.9-hour attachment that ended during a breaching event.

The team planned to add the biocompatible glues with the micro-texture design for testing during the 2018



Representation of micro-texture on a tag's suction cup edges.

right whale monitoring season. However, because so few right whales were located for testing, the team was unable to progress to the next stage of adding adhesives to the microtextured suction cups. The team recommends that adhesives be added when using these suction cups in future field trials.

Overall the project has completed the design, build and field testing of three different stiffnesses of microtextured suction cups. Initial analyses indicate that softer material micro-texture cups were extremely effective at minimizing sliding of the tag but were less resistant to bumping or breaching detachment, resulting in shorter than anticipated attachments. The firmer material in the Shore 60A cups led to more noticeable sliding, but apparently higher attachment forces resulting in longer attachment times. Analyses of field test results are ongoing.

Making progress on new suction cup materials will help the longer-term recording tags provide extended acoustic data collection timeframes. Such tag and attachment systems could apply to a broad range of endangered species in multiple Navy areas of interest. The products from this research will include micro-textured machined suction cups in the final form as determined from results of field testing.

About the Principal Investigators

Susan Parks is an associate professor in the department of biology at Syracuse University in Syracuse, NY. She specializes in bioacoustics, focusing on the use of sound for communication and the impacts of noise on development, behavior, sound production and reception. Dr. Parks holds a Ph.D. in Biological Oceanography from the Massachusetts Institute of Technology & Woods Hole Oceanographic Institution.

Douglas Nowacek is a professor of conservation technology with joint appointments in the Nicholas School of the Environment and the Pratt School of Engineering at Duke University. His research topics include the behavioral and acoustic ecology of marine mammals, the effect(s) of anthropogenic noise on marine mammals, and the development of technology for marine conservation research. Dr. Nowacek holds a Ph.D. from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution.

High Fidelity Acoustic and Fine-scale Movement Tags

Principal Investigator: Alex Shorter
Project Status: Ongoing, Project 27

NEED

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

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

PROJECT

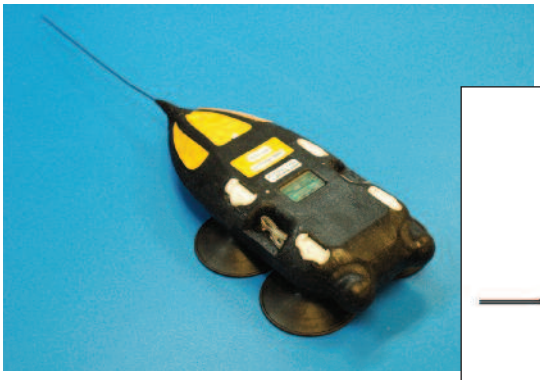
One type of acoustic tag often used in research and monitoring is the digital acoustic recording tag (DTAG). DTAGs are highly integrated, compact, low-power, high-fidelity acoustic bio-logging tags that are well suited for studying both deep diving beaked whales and large baleen whales. The combination of high-resolution acoustic and movement sensors make these tags key enabling technology for any behavioral response research.

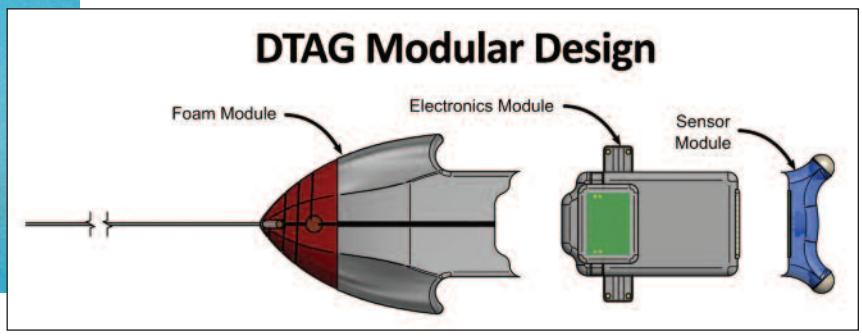
This project is focused on building a pool of new (third) generation DTAGs (DTAG-3s) and subjecting the DTAG-3 design to field testing by multiple researchers on a range of animals. Updates to the DTAG-3 design, previously funded by the ONR Marine Mammals and Biology (MMB) program, include lower cost, production efficiency, reduced size for small odontocetes, longer duration attachments and improved availability for researchers in the field.

An important aspect of this project is the tag leasing program, which is helping to make tags readily available and sustain tag improvements.

An important aspect of this project is the tag leasing program, which is helping to make tags readily available and sustain tag improvements. The tag pool is maintained at the University of Michigan. Users lease tags for their field work then return the tags to pool, where they are maintained, repaired (if needed) and updated or modified based on user feedback. The feedback, coming from researchers using the tags under rigorous field conditions, helps to evaluate tag field reliability and provide input to tag improvements. Following any appropriate maintenance or improvements, tags are returned to the lease pool and again become available for users.

The modular design of the leasing pool DTAGs enables incremental adjustments, rather than requiring overall tag redesign. The connector used for data offload and recharge was upgraded during 2018, as was the tag antenna. Both the leasing pool arrangement and the modular design make tag production more cost-effective while also supporting researchers' varied needs. As part of this project, 12 DTAGs have been built so far, as well as six core units. Tags from the leas-



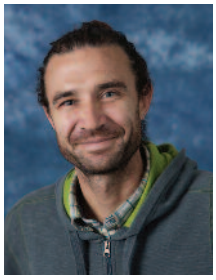


ing pool supported ten different projects and totaled 46 tag months during 2018. Requests for 2019 had reached 35 tag months by the close of 2018.

The DTAG-3 is a great example of a technology that is moving through the Navy's three marine resource programs—development was initiated under the ONR MMB program, demonstration and validation is occurring now under the LMR program, and implementation is occurring through use by the Navy's Marine Species Monitoring Program. This reflects the way in which these three Navy programs are coordinated to meet Navy needs.

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 at Urbana-Champaign.



MCS Trey Fowler

INVESTMENT AREA 4: STANDARDS AND METRICS

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

Bottlenose dolphin.

Ensuring consistent, agreed-upon standards and metrics provides multiple benefits.

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

Three ongoing projects and one new project are summarized in this section.

Ongoing

1. Project 6 Database and Metrics for Testing Automated Signal Processing for Passive Acoustic Monitoring
2. Project 18 Acoustic Metadata Management for Navy Fleet Operations
3. Project 28 Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems

New Start

1. Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar

Ongoing Projects

Database and Metrics for Testing Automated Signal Processing for Passive Acoustic Monitoring

Principal Investigator: John Hildebrand
Project Status: Ongoing, Project 6

NEED

N-0020-13 Demonstration and Evaluation of Platform-Independent Improvements to Automated Signal Processing of PAM Data

As PAM sensors continue to collect more and more data, methods for processing the data are time-consuming and costly. The Navy needs new PAM data processing tools that will increase efficiency and are designed for users with relatively little or no subject matter expertise. In addition, there is a need for a process by which these tools are evaluated against common, shared benchmarks.

PROJECT

Processing extensive passive acoustic monitoring (PAM) data sets to detect and classify marine mammal calls has typically relied primarily on trained acoustic data technicians. Automated data processing tools, called detectors and classifiers, also are used to detect marine mammal calls in passive acoustic monitoring (PAM) data and determine (i.e., classify) which species made the calls. These automated tools are continually evolving and offer the Navy more efficient methods for processing large amounts of acoustic data. Although the automated tools can reduce the number of personnel and associated resources needed to analyze acoustic data, different automated tools analyze data differently and it can be difficult to compare results.

Measures for evaluating automated detectors and classifiers are needed for evaluating tool performance. The ultimate goal of this project is to develop an extensive data set of marine mammal calls to use in developing robust detectors and classifiers and to develop standard metrics by which to compare the performance of the detectors and classifiers.

This project's team is developing both the evaluation data sets and the metrics needed to assess the performance of existing and future automated data processing tools for PAM data. The team is constructing marine mammal sound data sets specific to particular Navy training areas in the Pacific and Atlantic oceans, then composing a standardized set of metrics against which the performance of both existing and potential new automated tools can be evaluated.

> This project has engaged members of the marine mammal detection and classification community to develop a standardized set of metrics for evaluating the performance of automatic detector and classification outputs.

A Pacific data set that includes blue whale D-calls and multiple odontocete species calls was tested in 2015. A subsequent Atlantic data set was completed for 10 known call types: Gervais' beaked whale, Cuvier's beaked whale, Sowerby's beaked whale, Risso's dolphin, Atlantic white-sided dolphin, short finned pilot whale, Stenella species, blue whale (type A), minke whale (pulse train) and right whale (up-call), as well as two unknown dolphin click types (delphinid A and B) and unidentified dolphin.

This project has engaged members of the marine mammal detection and classification community to develop a standardized set of metrics for evaluating the performance of automatic detector and classification outputs. A metrics committee was formed in 2015 and its products are being designed to be universally applicable to both existing and potential new automatic detection tools for specific baleen whale calls and odontocete signals. New automated tools can be promulgated to all end-user analysts once they have met the minimum standards set by the metrics committee. Work in 2018 focused on finalizing case studies and manuscript preparation.

About the Principal Investigator

John Hildebrand has served as professor of oceanography at the Scripps Institution of Oceanography since 1995. He earned his Ph.D. in Applied Physics from Stanford University.

Key collaborators include Simone Baumann-Pickering and Ana Širović, Scripps Institution of Oceanography; Marie Roch, San Diego State University.

Short-finned pilot whale.
Suzanne E. Yin, permit 14451

Acoustic Metadata Management for Navy Fleet Operations

Principal Investigator: Marie Roch
Project Status: Ongoing, Project 18

NEED

N-0088-15 Marine Species Monitoring Data Collection Toolkit Development

Current Navy-funded marine biological resource surveys span a variety of survey protocols and produce geo-referenced data products that frequently cannot be used together due to a lack of established standards. Data protocols, formats, standards and quality assurance procedures (QA/QC) are all items that need to be addressed with the goal of standardizing across the Navy's Marine Species Monitoring Program and ensuring consistency within the scientific community. The Navy needs standard management of data and products in order to ensure that analysis and results are consistent and comparable.

PROJECT

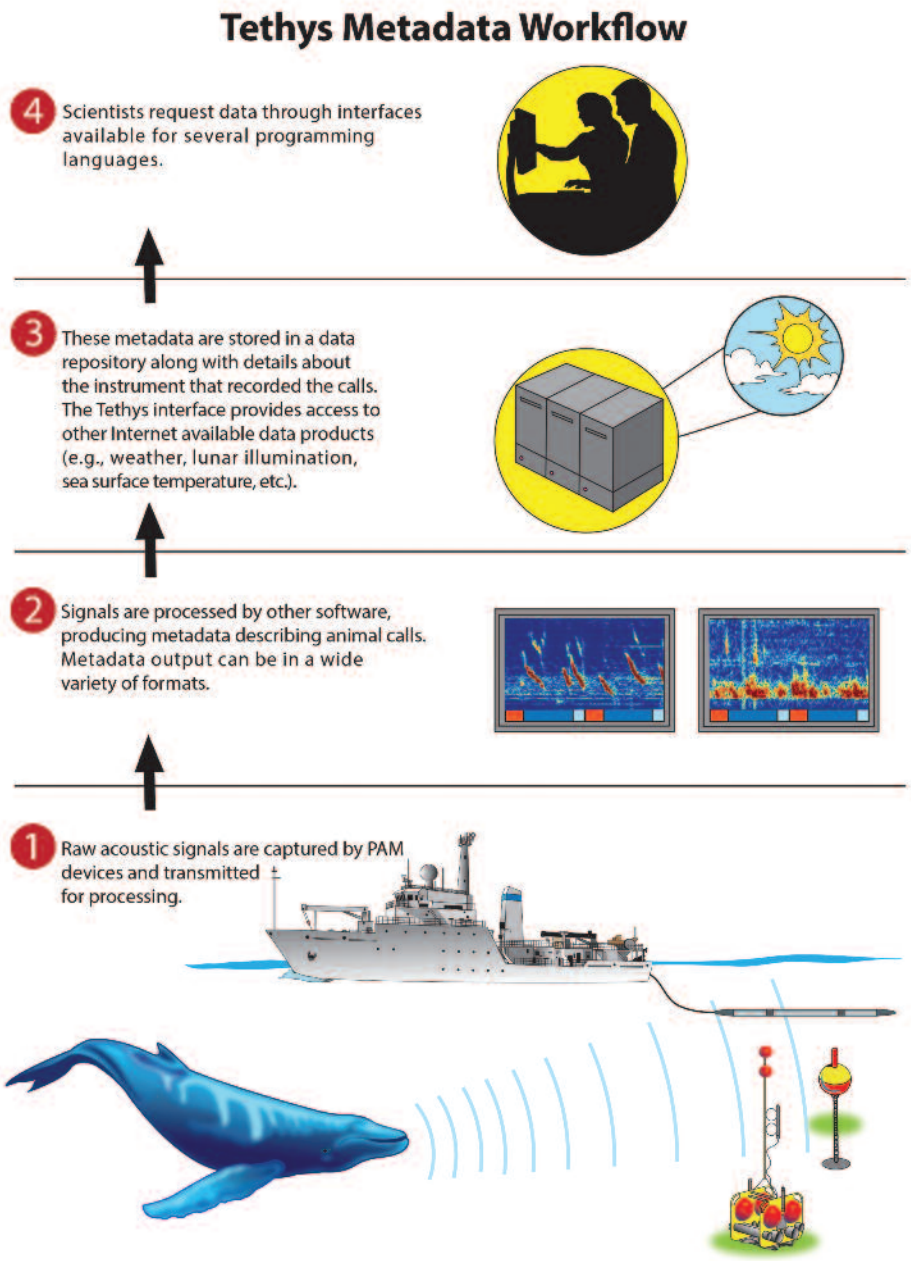
This project is conducting work to standardize long-term acoustic marine species monitoring records and to develop a reference database for Navy data management and reporting requirements. The project is using Tethys, a passive acoustic monitoring (PAM) metadata database sponsored by National Oceanographic Partnership Program. Tethys incorporates the expertise of PAM personnel at NOAA's Alaska, Northeast, Pacific Islands, Southeast and Southwest Fisheries Science Centers, as well as PAM experts at Scripps Institution of Oceanography and San Diego State University.

With previous funding, the project team has developed standardized data representations (schemata) describing instrumentation, effort, detections and localizations. This standardization within the Tethys database can be implemented on other systems and is becoming a community standard. These schemata provide a solid foundation for developing an official standard.

Under current funding, the project team is strengthening the capabilities of Tethys to make it more usable by the U.S. Navy, other federal agencies and the scientific community in general. Specific tasks have included providing additional data analysis and reporting facilities, identifying bottlenecks in performance as the existing databases continue to grow in size, and further developing the program's schemata for localization. These efforts will improve the Navy's ability to perform long-term marine species monitoring data management.

These efforts will improve the Navy's ability to perform long-term marine species monitoring data management.

The Tethys software version 2.4 was released in 2018. This version is capable of handling larger documents and processing queries more quickly. Work on a new graphical user interface (GUI) continued, providing an initial version for obtaining user feedback. The new version also reflects suggestions from the standards committee regarding schemata, including integrating whistle detectors. Ongoing work is integrating Tethys into Raven-X, an ONR-sponsored product for large-scale data analysis, which is currently being used at SPAWAR by Tyler Helble. When completed, it will allow Navy-generated data to be produced in the Tethys data format.



The standards development process under the ASA framework continued with work group meetings and draft products. This process will move the Tethys schemata towards an ANSI standard.

The project is co-funded by the Navy, NOAA and the Bureau of Ocean and Energy Management (BOEM). The project builds upon work previously funded by ONR.

About the Principal Investigator

Marie Roch is an interdisciplinary computer scientist whose work on the bioacoustics of marine mammals is internationally recognized. She is a professor at San Diego State University and is affiliated with Scripps Institution of Oceanography's Marine Acoustics Laboratories. Dr. Roch holds a Ph.D. in Computer Science from the University of Iowa.

Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems

Principal Investigator: Aaron Thode
Project Status: Ongoing, Project 28

NEED

N-0020-13 Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data

As PAM sensors continue to collect more and more data, methods for processing the data are time-consuming and costly. The Navy needs new PAM data processing tools that will increase efficiency and are designed for users with relatively little or no subject matter expertise. In addition, there is a need for a process by which these tools are evaluated against common, shared benchmarks.

PROJECT

Navy monitoring utilizes a variety of PAM methods including fixed range hydrophones, fixed single sensor hydrophones, hydrophones deployed on mobile unmanned underwater vehicles (such as sea gliders, wave gliders, etc.), tags and towed cabled hydrophone arrays. Several U.S. federal agencies and departments, including the Navy, desire consistent standards for how to implement PAM of marine mammals for monitoring and compliance purposes. Specifically, the U.S. Navy, National Marine Fisheries Service and the Bureau of Safety and Environmental Enforcement, are partnering in an effort to develop a standard for towed cabled PAM.

This project helps to support development of an ASA-sponsored ANSI standard on towed cabled PAM systems and operations for monitoring and mitigation purposes. Towed PAM uses hydrophones towed behind surface vessels. The hydrophones transmit data via either cable or telemetry to a central recording station. Although towed PAM comprises a relatively minor portion of Navy marine mammal PAM efforts, the technology is perceived as the most mature and thus the best candidate for starting a standards process.

> Developing a standard for towed cabled PAM by a professional society would create both greater simplicity in assigning PAM contracts and greater consistency in PAM operations.

In 2017 a working group met at NOAA headquarters in Silver Springs, Maryland to review the draft standard report and map out routes forward. The outcome of the meeting was to create subcommittees to focus on different portions of the standard. The groups currently formed are the "Acoustic Cluster Table" and "Operator Qualifications." The former deals with standardizing assumptions one can make about frequency content and source level of various marine mammal species, while the latter deals with basic training and documentation for PAM operators in the field.

Work during 2018 focused on defining the "Acoustic Cluster Table," which is roughly completed. This was prerequisite to the Noise and Reporting subgroup beginning work. The "Operator Qualifications" subcommittee continued its work to define the basic training and documentation for PAM operators in the field. A draft standard is anticipated to be ready for voting by the Acoustical Society of America by Fall 2019.

Towed hydrophone array.
Martijn van Riet

Developing a standard for towed cabled PAM by a professional society would create both greater simplicity in assigning PAM contracts and greater consistency in PAM operations across multiple organizations and contractors. Successful implementation of this standard for towed arrays would provide a template for other PAM technology standards as various technologies mature. The standard will address requirements and recommendations for initial planning (including guidelines for when PAM is not appropriate for a planned field operation), hardware, software, training, real-time mitigation and monitoring procedures and performance validation.

About the Principal Investigator

Aaron Thode, full research scientist at the Scripps Institution of Oceanography Marine Physical Laboratory, received his Ph.D. in Oceanography from Scripps in 1999. Dr. Thode's research has included developing automated detection, classification and tracking methods of migrating bowhead whales; using vertical arrays to localize whale sounds in range and depth from a single deployment; validating call density estimation methods using experimental data and measuring responses of bowhead whales to natural and industrial noise.

New Start Project

Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar

Principal Investigators:
Elizabeth Henderson and Susan Jarvis
Project Status: New start, Project 34

NEED

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

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

PROJECT

This project is taking a collaborative approach to develop a set of standardized detectors and classifiers, along with a set of standardized nomenclature for Navy sonar signals. The project team includes Navy investigators who will assess the efficacy and broad applicability of existing sonar detectors, provided with support by non-Navy researchers. The group also will

> This [project] will promote comparability of results of independent research on the effects of Navy training and testing activities, including Navy sonar, on marine life.

ensure that the greater research and signal detection communities are involved in developing a standardized and generalizable sonar detector.

Project responsibilities are carefully defined to protect classified information while working toward standardized non-classified methods. Literature reviews will identify existing detectors and identify issues regarding the detection and classification of sonar signals. In addition, further literature review will identify descriptions of sonars that are already in the public domain (e.g., within environmental impact statements or published papers). The Navy sonar classification guidelines will be reviewed to inform selection of descriptive nomenclature. During this phase, and during the compilation and validation of data sets with sonar, the Naval Undersea Warfare Center (NUWC) sonar warrant officer will be consulted to ensure that investigators know what the source properties of each sonar signal should be and that any nomenclature used is unclassified. An unclassified standardized descriptive nomenclature for sonar signals will be developed.

Navy members of the project team will compile a standardized passive acoustic data set from both Navy range data (from three different locations) and non-Navy recorded data (from two or three different types

USS Arleigh Burke (DDG 51) and USS Forrest Sherman (DDG 98).
MC3 Gitte Schirrmacher

of recorders). The data set will include three or four examples of Navy sonar, such as hull-mounted sonar (e.g., AN/AQS-53C) operating in two different modes, helicopter-dipping sonar (e.g., AN/AQS-22) and an active sonobuoy sonar (e.g., AN/SSQ-62 DICASS). Working with multiple types of sonar sources will help to set a benchmark of the necessary characteristics of broadly applicable sonar detectors.

Navy members of the project team will then process the data set using two to four solicited detectors (from academic and independent groups) alongside the Space and Warfare Center (SPAWAR) detector. Results will be summarized using standardized performance metrics. This will help to quantify and evaluate the performance of these existing detectors against known sources in multiple environments. From this evaluation a new detector (or set of detectors) can be developed (or an existing detector can be adjusted). The final detector(s), recommended features and classifier(s) will be made available to the participating organizations and the wider acoustics research community.

This effort will provide validated automated detectors/classifiers for detecting the presence of sonar in marine mammal PAM data sets. It will also provide recommendations on tuning the characteristics of these detectors for optimal use. In addition, standardized unclassified sonar nomenclature will be made available to researchers. This will promote comparable results from independent research on the effects of Navy training and testing activities, including Navy sonar, on marine life.

About the Principal Investigators

Elizabeth Henderson is a bioacoustic scientist with the Navy Marine Mammal program at the Space and Naval Warfare Systems Center. Dr. Henderson earned her Ph.D. in marine biology and biological oceanography at the University of California, San Diego. She focuses on bioacoustic and noise impact analyses for environmental compliance.

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

INVESTMENT AREA 5. EMERGENT TOPICS

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

There are two projects summarized in this section, one ongoing and one new start.

Ongoing

1. Project 10 The Effects of Noise on Marine Mammals: Progress Since 1995.

New Start

1. Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources.

Ongoing Project

The Effects of Noise on Marine Mammals: Progress Since 1995

Principal Investigators:
Christine Erbe and Dorian Houser
Project Status: Ongoing, Project 10

NEED

N-0001-13 Assessing and Mitigating the Effects of Noise on Living Marine Resources

The Navy needs new data to improve the acoustic and explosive impact assessments for marine species. Priority topics include better methods to assess the potential effects of underwater sound or cost-effective methods to mitigate the impacts of underwater sound.

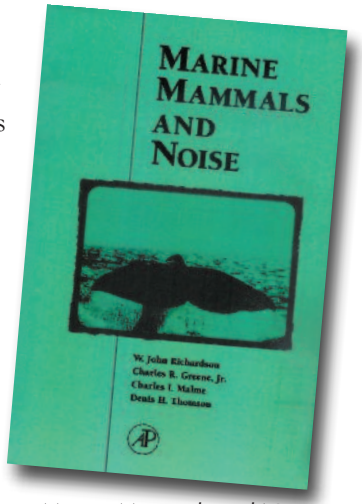
PROJECT

The book *Marine Mammals and Noise* (Richardson et al. 1995) has been the single most cited resource for information on the effects of noise on marine mammals since its publication. It has been a valuable resource for the Navy, environmental planners, regulators and scientists. However, in the last 20+ years the literature related to the issue of marine mammals and noise has expanded greatly and there is more information to consider when assessing effects of noise on marine mammals.

This project aims to gather, analyze and summarize all updated information available pertaining to the effects of noise on marine mammals. The information will be incorporated into an authoritative tool that marine resource specialists within the Navy can use to develop at-sea environmental compliance documentation. This tool will enable the Navy to strengthen its ocean science technical workforce.

The LMR program is one of four stakeholders contributing funds to this project. The other contributors are ONR MMB program, the NOAA and the International Oil & Gas Joint Industry Programme. Tasks funded by the LMR program are

1. Developing a publicly accessible database of literature on marine mammal bioacoustics
2. Developing a standardized database of studies conducted on marine mammal hearing
3. Analyzing and summarizing available data on the sounds produced by marine mammals and on marine mammal hearing
4. Analyzing available information and



Marine Mammals and Noise, published in 1995, is the single most cited source for marine mammal data. This LMR project will develop an updated source for information on marine mammal bioacoustics.

preparing a recommendation on how marine mammal bioacoustic data can inform both conservation efforts and the management of marine resources.

Work on these tasks is largely complete and efforts during 2018 focused on compiling the written report.

Project results will support the Navy's environmental compliance process and provide essential information necessary to improve the acoustic and explosive impact assessments of marine species.

Project results will support the Navy's environmental compliance process and provide essential information necessary to improve the acoustic and explosive impact assessments of marine species.

About the Principal Investigators

Christine Erbe is the director of the Center for Marine Science & Technology at Curtin University in Perth, Western Australia. Dr. Erbe has worked on underwater noise impacts on marine mammals for Fisheries & Oceans Canada, worked as a private bioacoustic consultant, and was director of JASCO Applied Sciences Australia, a consultancy in underwater noise. She earned her Ph.D. in Geophysics from the University of British Columbia, Canada.

Dorian Houser is the director of conservation and Biological Research at the National Marine Mammal Foundation. Dr. Houser has spent nearly two decades in the study of how anthropogenic sound affects marine mammals and has been involved in the development of numerous environmental impact statements for the U.S. government. He earned his Ph.D. in Biology from the University of California, Santa Cruz.

Humpback whales.

New Start Project

Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources

Principal Investigator: Peter Dahl
Project Status: New start, Project 35

NEED

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

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

PROJECT

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

For the near-field measurements, the team will deploy acoustic measurement instrumentation at two sites, arranged to measure both a direct waterborne path between the explosive source and the receiver and a path reflected from the seabed. A vertical line array (VLA) will be used to measure the bottom reflection and tourmaline sensors deployed from a surface buoy will be used to measure the direct waterborne path. The surface buoy will house an airborne hydrophone to provide more information on the location of the explosion. Data from both near-field sites will be compared and used to estimate the location of the explosion.

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

There will be three far-field measurement sites, arranged to characterize propagation effects. These will be configured to provide data on effects of varying depths and distances from the explosive source. Each site will be equipped with VLAs to collect site-specific data, which will encompass varying depths (up to 1000 meters), thermocline influences and overall acoustic field. The equipment also will collect essential environmental data, such as water sound speed and surface wave spectra, needed for the modeling and interpretation of the observations of acoustic propagation.

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

underwater sound fields from explosives at both close and long ranges. This is critical to improving the Navy's analysis of the effects of explosive sources on marine species.

About the Principal Investigator

Peter Dahl is a senior principal engineer in the acoustics department and a Professor in the University of Washington's Department of Mechanical Engineering.

Dahl's research is in areas of acoustics with a primary focus on underwater sound. Dr. Dahl earned his Ph.D. from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1989.

Altan Turgot from the Naval Research Laboratory is key collaborator.

An explosive detonation.
MC2 Josh Bennett

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. Three ongoing partnerships were underway during 2018.

1. Sonobuoy Liaison Working Group
2. Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales
3. Developing Tools for Acoustic-only Behavioral Response Studies at Navy Instrumented Ranges

Ongoing Projects

Sonobuoy Liaison Working Group

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

The Sonobuoy Liaison Working Group (SLWG) assisted the LMR program in submitting a request to augment the sonobuoy allotment for FY18. The request was generously granted by Naval Air Systems Command (NAVAIR), which increased the number of sonobuoys available for researchers this year. The base request of 480 sonobuoys was augmented by 192 for a total of 672 devices. This enabled the LMR program to meet some of the added requests for the 2018 field season. These sonobuoys are playing a significant role in expanding our data sets, and thus knowledge, related to where animals occur and when they are present.

The request to augment the sonobuoy allotment for FY18…was generously granted by Naval Air Systems Command…for a total of 672 devices.

Projects and organizations receiving sonobuoys are listed in the following table.

PROJECT	ORGANIZATION
Atlantic Marine Assessment Program for Protected Species (AMAPPS) and North Atlantic Right Whale aerial surveys	NOAA Northeast Fisheries Science Center
California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys	Scripps (UC San Diego)
Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas (DECAF-TEA) & Controlled Exposure Experiments	Naval Undersea Warfare Center (NUWC)
Gulf of Mexico Assessment Program for Protected Species (GOMAPPS) surveys	National Marine Fisheries Service Southeast (NMFS SE)
International Whaling Commission Pacific Ocean Whale and Ecosystem Research (IWC POWER), North Pacific Research Board (NPRB), Arctic integrated ecosystem research program (IERP), and NOAA Pacific Marine Environmental Laboratory surveys	NOAA Marine Mammal Laboratory/ Alaska Fisheries Science Center
Southern California (SOCAL) offshore surveys	National Marine Fisheries Service Southwest (NMFS SW)
Washington/Alaska surveys	Bio-Waves, Inc.

Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales

The Navy needs to be able to monitor sites of interest such as Navy training and testing areas. Passive acoustic monitoring (PAM) is a proven means of detecting, classifying, and localizing vocally active marine mammals. This project, a collaboration between the LMR program and the Department of Defense Environmental Security Technology Certification Program (ESTCP), is working to validate technologies that can provide near real-time data of marine mammal occurrence. This technology could increase the efficiency of Navy monitoring efforts.

The overall objectives of this project include:

1. Demonstrating year-round, large-scale near real-time acoustic surveillance of four species of endangered baleen whales (fin, humpback, sei and right whales) from three different autonomous platforms
2. Validating real-time acoustic detections using audio recorded in-situ, along with airplane-, ship- and land-based visual observations
3. Developing best practices for integrating real-time acoustic detections from autonomous platforms into persistent visual monitoring.

This technology package offers a useful tool to the Navy's Marine Species Monitoring Program that can augment visual survey data…

The combined hardware/software system used is a digital acoustic monitoring instrument (DMON) and low-frequency detection and classification system (LFDCS). The DMON registers the underwater sounds and the LFDCS automatically analyzes the sounds to determine if they are from any of the four baleen whales of interest. A subset of signal data from the platforms are periodically transmitted to an Iridium satellite and then downloaded to a shore-based system. The satellite data are reviewed by a human analyst to verify the system's detection and classification.

This DMON/LFDCS system has been deployed on the three autonomous platforms—moored buoy, wave glider and Slocum glider. The platforms were first deployed in the Atlantic, off the New England coast, in 2015 and again in 2016. Additional deployments occurred in 2017. The autonomous platform deployments were supplemented by co-located visual monitoring from ships, aerial surveys and land-based observation platforms to provide comparison data on the visual and acoustic detection rates for the four endangered species.

The moored buoy platform that was deployed between March 2015 and March 2016 suffered electrical issues, vandalism and noise. The buoy configuration was adjusted and redeployed between September 2016 and October 2017. The acoustic data from these deployments were compared to visual data collected during 36 aerial survey flights during 2015 and 2017.

The Slocum glider was deployed multiple times in 2015 and 2016, including a coordinated deployment in Great South Channel off of Massachusetts that included both a Naval Oceanographic Office (NAVO) Slocum glider and the Woods Hole Oceanographic Institution (WHOI) glider. This successful one-month deployment demonstrated the use of the DMON/LFDCS package on a Navy asset and was a first step at transitioning the

system to the Navy's Marine Species Monitoring Program. Related to that effort, NAVFAC Atlantic staff was trained on the deployment, recovery and analysis of the data. An independent mirror data analysis of the NAVO glider data by both Navy and Northeast Fisheries Science Center staff provided highly consistent results for all four species. An additional WHOI Slocum glider deployment was conducted in the Gulf of Mexico during 2017 to demonstrate detection capabilities for Navy stakeholders.

By the end of 2017 the project had demonstrated operational use of Slocum gliders and moored buoys. The wave glider platform had some challenges with self-noise, and attempts were made to mitigate the noise. Redeployment of the wave glider platform occurred in late 2016.

Analyses and report development were the project focus during 2018.

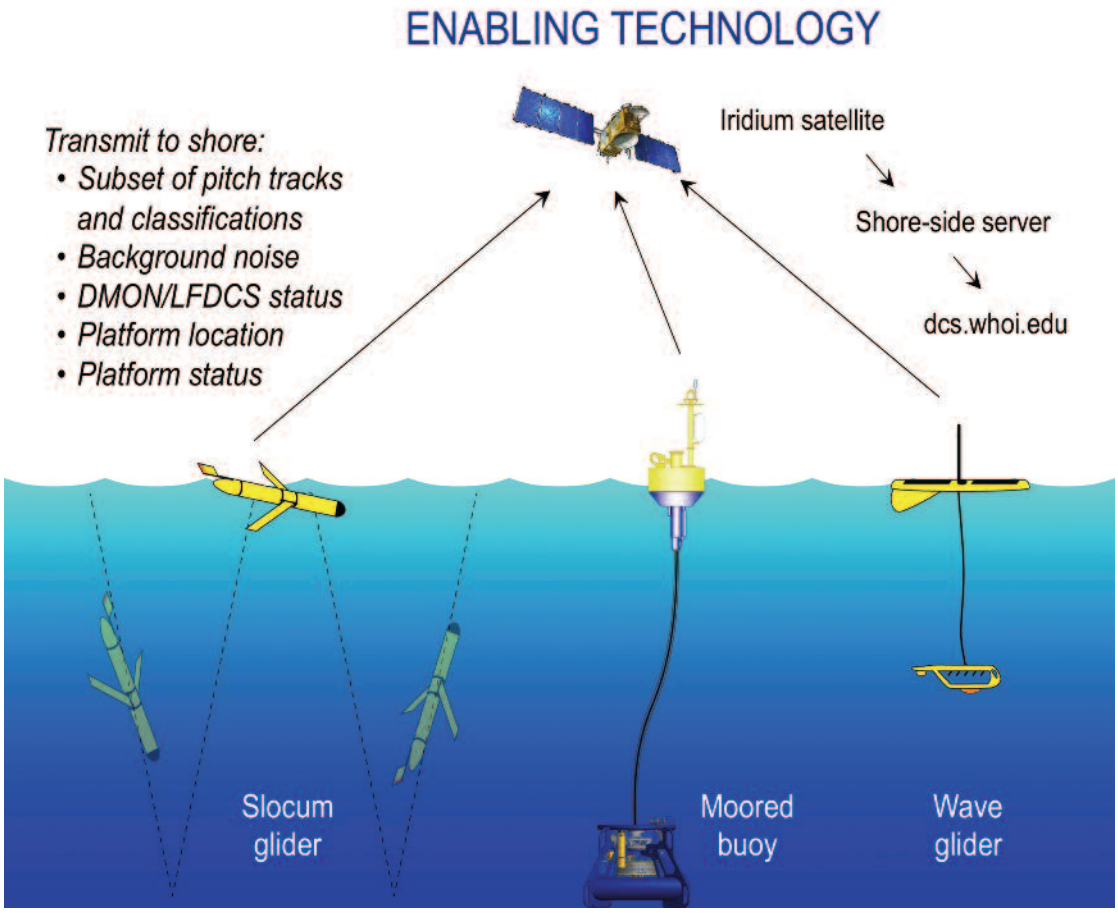
All platforms report detections to a publicly available website (dcs.whoi.edu), where platform tracks, detection information and pitch tracks are examined and analyzed by scientists. This technology package offers a useful tool to the Navy's Marine Species Monitoring Program that can augment visual survey data in areas of Navy interest, and the online data availability improves access for analyzing baleen whale presence.

Principal Investigators

Cara Hotchkin
Naval Facilities Engineering Command Atlantic

Mark Baumgartner
Woods Hole Oceanographic Institution

Sofie Van Parijs and Peter Corkeron
Northeast Fisheries Science Center.



Developing Tools for Acoustic-only Behavioral Response Studies at Navy Instrumented Ranges

The Navy needs information about how protected marine species respond to sound exposures in order to meet permit requirements for at-sea training and testing. This project is developing automated tools that will make data analysis and reporting of marine mammal behavior and response on Navy instrumented ranges more efficient.

Behavioral response studies typically entail at-sea, boat-based visual detection, tagging and tracking of animals in coordination with simulated sound sources and Navy ships. While this approach provides critical information, it is logistically difficult and time-consuming. An alternative, and complementary, method could apply software tools to the extensive existing PAM data sets to study the animals' responses to sound.

The Space and Warfare Systems Center Pacific (SSC Pacific) has been collecting data from hydrophone arrays on Pacific Missile Range Facility (PMRF) to acoustically monitor marine mammal activity since 2003. Such long-term monitoring has created robust acoustic data sets, both in types and quantity of data. In addition, relatively recent advances in localization software development have allowed SSC Pacific to acoustically detect, localize and track several species of whales including beaked, humpback, minke, Bryde's, fin, sei and sperm whales. With appropriate new tools, this combination of data and software advancements could offer an opportunity to conduct acoustic behavioral response studies on Navy instrumented ranges.

This partnership among ONR, LMR, and Commander, Pacific Fleet is developing a suite of tools needed to efficiently conduct basic, acoustically based behavioral response assessments. The tools will be used to support both an ONR effort, titled "Behavioral Response Evaluations Employing Robust Baselines and Actual Navy Training (BREVE)," and ultimately the ongoing monitoring reporting required as part of permits.

Within the LMR portion of this effort, the project team is developing three software tools to help analyze metrics needed for acoustic behavioral response studies. Each tool and the associated work completed thus far is summarized below.

These three tools will support acoustic behavioral response studies and monitoring of marine mammals on instrumented Navy ranges.

- **Tool 1. Interface for acoustic modeling software.**
  This tool will automatically estimate sonar sound pressure levels (SPL) and sound exposure levels (SEL) to tracked animals.

  The interface has been designed using available Navy standard models in order to automate the SPL/SEL estimation process. The software has been completed, and SPL and SEL levels have been automatically assigned to hundreds of minke whale tracks on the PMRF range. The team will continue to validate the model with known sources, as well as apply the software to additional species and timeframes.

  Additionally, the tool has been expanded to estimate the transmission loss between marine mammal sources on the range and the hydrophones receiving the signals. Software has also been completed to automatically measure the received level of the marine

mammal calls. Testing is currently underway to validate the accuracy of the measurements. The goal is to be able to automatically estimate the source level of several species of marine mammal calls on the range. The team is currently testing this method with minke whales, where initial results indicate a Lombard effect (the animal source level increases with increasing ambient noise).

- **Tool 2. Automated track kinematics software.**
  This tool will group whale localizations into tracks and automatically extract relevant swim kinematics (e.g., animal's speed, direction, depth, etc.).

  The methods being developed within this tool will support automatic implementation of metrics developed under the BREVE project. This will allow bulk processing of tracks, reducing the need for human operator involvement. Methods were adapted from Naval Undersea Warfare Center's Multi-Hypothesis Tracker (MHT) and were successfully applied to both minke whale and humpback whale tracks. The output from the MHT provides the input to additional custom software that automatically measures whale kinematics.

  During 2018, additional kinematics software updates were completed to more accurately estimate whale instantaneous headings. The Behavioral Change Point Analysis software was modified for this purpose.

  These data products have now been applied to hundreds of minke whale tracks and are currently being reviewed by the St Andrews BREVE statistical team to look for differences before, during and after Navy sonar exercises. Several journal papers are currently in press.

- **Tool 3. Automated classifier for track information.**
  This tool will help to process the thousands of tracks contained in archived data sets and will be applied to new data.

  This effort began by using available classifiers, with modifications as needed to work on the PMRF and the Southern California Offshore ranges. Initial results were presented at the 2018 Detection, Classification, Localization, and Density Estimation Workshop in June.

  Subsequently completed work has included context-based classification (adding additional classification by looking at groups of calls that are likely emitted by the same animal). Minke, humpback, sperm, Bryde's, fin and sei whales can now be classified automatically, with the caveat that some fin and sei non-song bouts are not distinguishable (combined visual/acoustic surveys may be needed to fully separate the two types, if at all possible). SPAWAR Systems Center Pacific (SSC-PAC) is currently developing automated classification for blue whales, a newly detected species on PMRF.

  Methods from this project have been transitioned to the ONR-sponsored project (Using Context to Improve Marine Mammal Classification, Marie Roch). SSC-PAC is continuing to work with Dr. Roch and her team to broaden the methods for use on hydrophone pairs with clock drift. Initial results show significant improvement in classification of right whales from existing data sets on the east coast.

These three tools will support acoustic behavioral response studies and monitoring of marine mammals on instrumented Navy ranges. This information will be used to inform analysis of impacts from Navy sound sources and potentially to inform development of criteria and thresholds for behavioral response. Additionally, tools and methods have already transitioned to assist other ONR- and LMR-sponsored projects.

Principal Investigators

Tyler Helble
Space and Naval Warfare Systems Center.

Elizabeth Henderson
Space and Naval Warfare Systems Center.

LOOKING AHEAD

LOOKING AHEAD

In 2019 we look forward to seeing several additional publications, results, methods and technologies from LMR-funded research transition into application within the Navy's environmental compliance process. Several LMR projects will be completed in 2019 and become available for transition or further investigation.

LMR intends to fund several additional projects from our Fiscal Year 2019 (FY19) Broad Agency Announcements. These new projects may include studies on low-frequency whale hearing, sea turtle hearing, extension of tag attachment duration, and further advancements and validation of passive acoustic density estimation methods. A few of these studies will leverage other federal partners support, including Office of Naval Research (ONR), the Bureau of Ocean Energy Management (BOEM), the National Oceanic and Atmospheric Administration (NOAA), and the Marine Mammal Commission. We are able to maximize value and reduce costs by collaborating on topics of similar interest. These studies will be initiated in FY19 to ensure that results and methods will be available in time to be incorporated into the Navy's next environmental compliance cycle.

Looking beyond 2019, LMR will continue to invest in tools, technologies and methods that will enable us to collect marine species data and investigate critical questions about the effects of Navy training and testing activities. The oceanic environment is a challenging and expensive place to study. Many of the tools and technologies needed to assist the Navy's Marine Species Monitoring Program in meeting monitoring requirements in a cost-effective manner are not readily available. These tools and technologies will be necessary to sustain at-sea training and testing in response to environmental permit requirements.

The ongoing collaboration and partnership of LMR, ONR and the Navy's Marine Species Monitoring Program will expand what we know about the potential effects on marine species from sonar and explosives and will continue to enable us to invest in priority research topics. In addition, the LMR program will maintain our close partnerships with other programs, agencies and countries—including the Environmental Security Technology Certification Program (ESTCP), BOEM, NOAA's National Marine Fisheries Service, and the navies in the United Kingdom, France, Norway and the Netherlands—to build on shared interests and more effectively leverage investments to achieve common goals.

As always, this work ultimately is about our Sailors and our ability to maintain an effective and resilient Navy while being good stewards of the environment. LMR research will continue to directly support the Navy's ability to train and test at-sea and preserve core Navy readiness capabilities.

Humpback whale.

LMR Publications

Included here is a list of publications that became available in 2018 and that were partially or fully funded by the LMR program. These publications are of great value to the Navy's at-sea environmental compliance process and directly feed into the NEPA, MMPA, and ESA compliance documentation.

For a list of publications from prior years, please see the previous LMR program reports, available at navysustainability.dodlive.mil/lmr

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Sardines.

Acronyms and Abbreviations

3S3.....Sea mammals, Sonar, Safety project phase 3
ABR.....Auditory brainstem response
AEP.....Auditory evoked potentials
ANSI.....American National Standards Institute
ASA.....Acoustical Society of America
ASCR.....Acoustic spatial capture recapture
ASSR.....Auditory steady-state response
ATA.....Advanced Technology Attachment
AUTEC.....Atlantic Undersea Test and Evaluation Center
AUV.....Autonomous Undersea Vehicles
BAA.....Broad Agency Announcement
BOEM.....Bureau of Ocean Energy Management
BREVE.....Behavioral Response Evaluations Employing Robust Baselines and Actual Navy Training
BRS.....Behavioral Response Study
CAS.....Continuously active sonar
CEE.....Controlled exposure experiment
CSEE.....Coordinated sonar exposure experiments
CT.....Computerized tomography
DCLT.....Detection, classification, localization, and tracking
DET.....Detection error trade-off
DICASS.....Directional command activated sonobuoy system
DIFAR.....Directional low-frequency analysis and recording
DMON.....Digital acoustic monitoring instrument
DSP.....Digital signal processor/processing
DTAG.....Digital acoustic recording tag
EIS.....Environmental Impact Statement
ESA.....Endangered Species Act
EVREST.....Evoked Response Study Tool
GIS.....Geographical information system
GPL.....Generalized Power Law
GPS.....Global positioning system
ICMP.....Integrated Comprehensive Monitoring Plan
IPR.....In-progress Review
IRAP.....Integrated Real-Time Autonomous Passive Acoustic Monitoring
ISO.....International Organization for Standardization
kHz.....kilohertz
LF.....Low frequency
LFDCS.....Low-frequency detection and classification system
LMR.....Living Marine Resources
LMRAC.....Living Marine Resources Advisory Committee
M3R.....Marine Mammal Monitoring on Ranges
MFAS.....Mid-frequency active sonar
MMPA.....Marine Mammal Protection Act
MSDD.....Marine Species Density Data
NAEMO.....Navy Acoustic Effect Model
NEPA.....National Environmental Policy Act
NAVAIR.....Naval Air Systems Command
NAVFAC EXWC.....Naval Facilities Engineering and Expeditionary Warfare Center
NAVO.....Naval Oceanographic Office
NMFS.....National Marine Fisheries Service
NMMF.....National Marine Mammal Foundation
NOAA.....National Oceanic and Atmospheric Administration
OE.....Opportunistic exposure
ONR.....Office of Naval Research
ONR MMB.....Office of Naval Research Marine Mammal Biology
OPNAV N45.....Chief of Naval Operations Energy and Environmental Readiness Division
PADN.....Portable Acoustic Data Node
PAM.....Passive acoustic monitoring
PAS.....Pulsed active sonar
PMRF.....Pacific Missile Range Facility
PTS.....Permanent threshold shift
RHIB.....Rigid hulled inflatable boat
RDT&E.....Research, development, test and evaluation
ROC.....Receiver-operator curves
ROCCA..Real-time Odontocete Call Classification Algorithm
SCC.....Submarine Command Course
SCORE.....Southern California Offshore Range
SEL.....Sound exposure levels
SLWG.....Sonobuoy Liaison Working Group
SOCAL.....Southern California
SOCAL-BRS.Southern California Behavioral Response Study
SPAWAR.....Space and Naval Warfare Systems Center
SPL.....Sound pressure levels
SSC Pacific.....Space and Naval Warfare Systems Center Pacific
SYSCOM.....System Command
TRC.....Technical Review Committee
TTS.....Temporary threshold shift
VLA.....Vertical line array

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

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navysustainability.dodlive.mil/lmryir