LMR

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

2017

SCIENCE • STEWARDSHIP
living marine RESOURCES
NAVY READINESS

May 2018

2017 LMR Program Report

STATUS OF THE LIVING MARINE RESOURCES PROGRAM

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Cover image: Gray whale. Back Cover images: Clockwise from left: MCS2 Ryan Utah Kledzik; MCS1 Ryan Riley; MSC Jacob Holloway.
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.

INTRODUCTION

Humpback whale.

A WORD FROM THE PROGRAM MANAGER

I am excited to share with you the 2017 Living Marine Resources (LMR) Program Annual Report. Throughout 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 new Environmental Compliance Overview section (page 8) to learn more about how the LMR program supports the Navy's at-sea environmental compliance process.

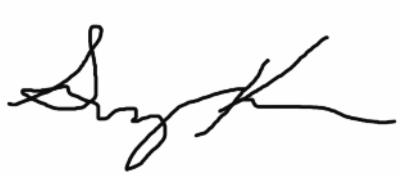
During 2017, the LMR program was managing 28 projects, all carefully selected to meet specific Navy-defined needs. Of the 28 projects, four reached their conclusion during 2017 and are being transitioned to the end users. Of the remaining 24 projects, 20 are ongoing and four are new efforts. Sixteen publications and technical reports, resulting directly from LMR supported projects or using data from LMR projects, were produced. These publications provide credible scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) environmental planners, regulators, scientists and other stakeholders.

A key focus for the program this past year has been risk threshold criteria, which are crucial to the Navy's analyses of potential impacts to marine species from training and testing activities. LMR projects collect important animal hearing and behavioral response data needed to develop the criteria and thresholds. One of the LMR program's completed projects from this year, Project 14 (page 27), obtained hearing data from eight individual killer whales ranging in age from 12-52 years. In fact, that project alone more than doubled the number of individuals for which we have hearing data. Other LMR projects are focused on advancing and applying knowledge to marine mammal tag technology, behavioral response research methods, acoustic recording devices and processing tools, and scientific standards for collecting and managing the data.

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.

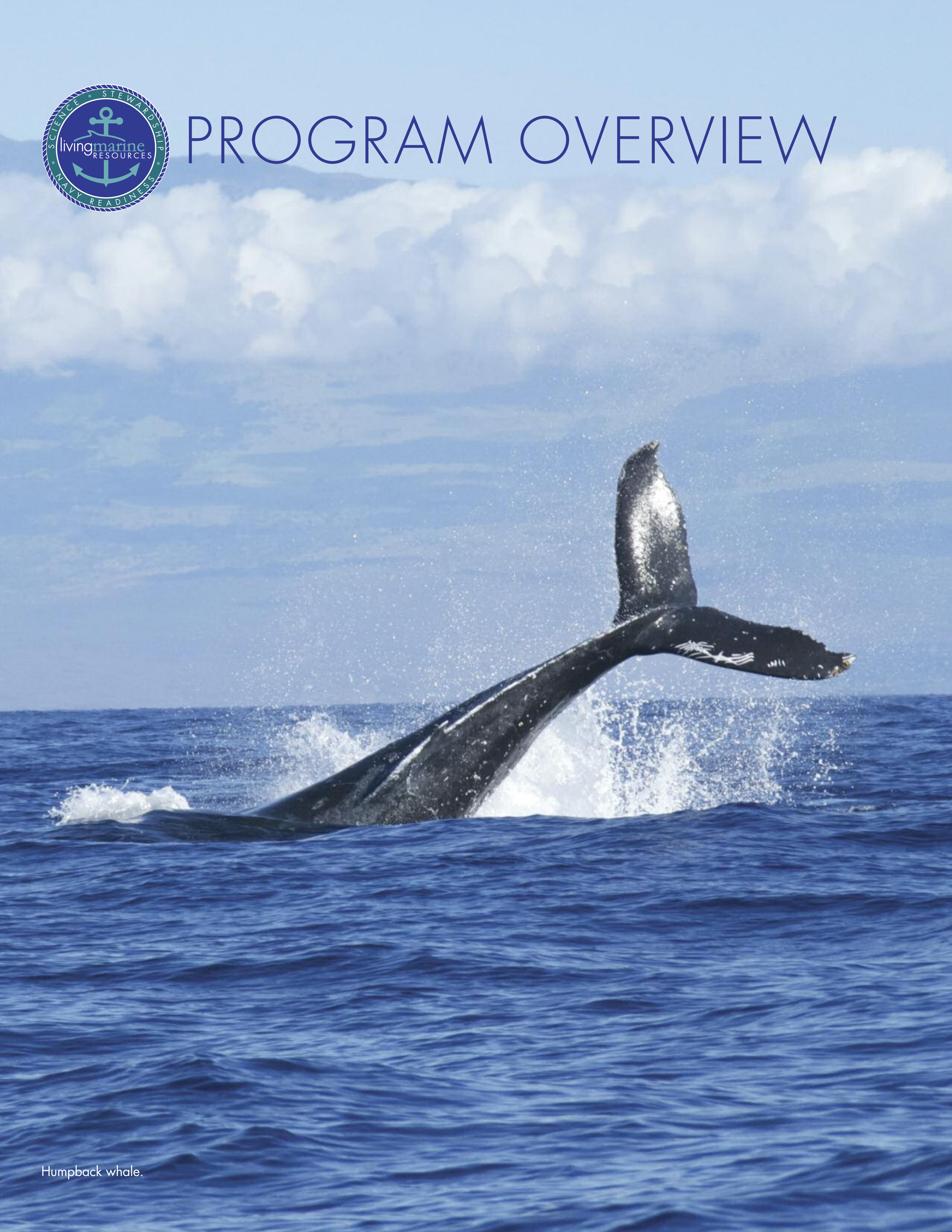
Anu Kumar, Program Manager

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 on the right track, 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



Humpback whale.

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.

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.

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.

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

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.

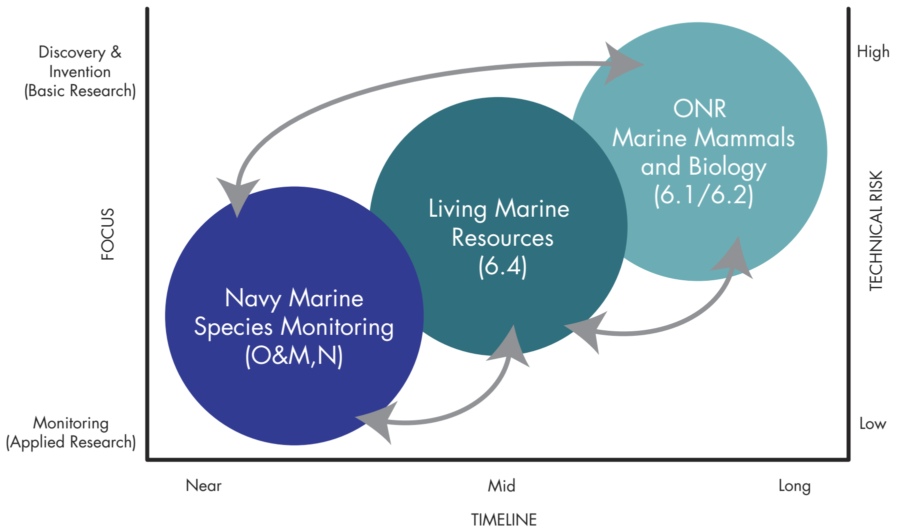
Without permits and associated environmental compliance, the Navy risks not being able to train or test. Without training and testing, the Navy cannot be ready to meet its mission. Environmental compliance is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

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.

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

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.

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.

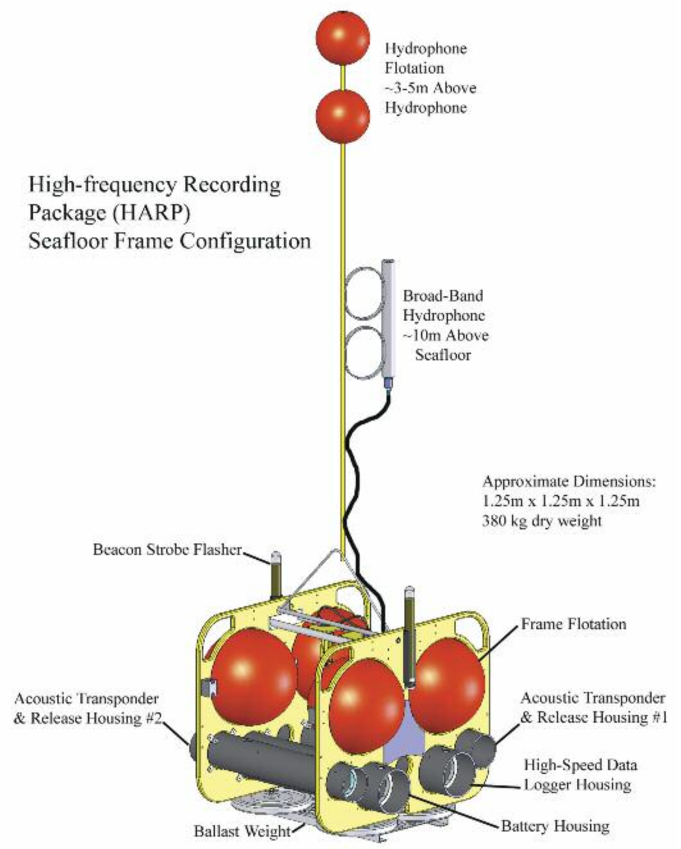
Cuvier's beaked whales.
Gregg Schorr, permit 15330

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.

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.



The HARP, used for Navy range acoustic monitoring, was initially developed and tested under research funding from ONR then moved to the LMR program for field demonstration and improvements.

As the chart on page 9 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. For example, most of the autonomous passive acoustic monitoring devices, including the high-frequency acoustic recording package (HARP) system, were initially developed under research funding from ONR. This was followed by LMR-funded field demonstrations, which revealed needed modifications and resulted in refinements. These devices are now used as a reliable component of the monitoring program and represent a successful transition from basic research to the end user. In another case, a whole research topic—hearing studies on odontocetes (toothed whales)—was transitioned from ONR to LMR because much of the basic development had been accomplished. 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.

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
- Chief of Naval Operations for Information Dominance (N2/N6)

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

LMRAC members provide critical Navy user perspectives.

MCS2 Catherine Bland

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.

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.

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

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 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, gliders and REMUS 600s. This investment area aligns with the goals of the Navy's Task Force Ocean to make every Navy platform a sensor for data collection.

Fin whale.

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.

Cuvier's beaked whale.

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 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.

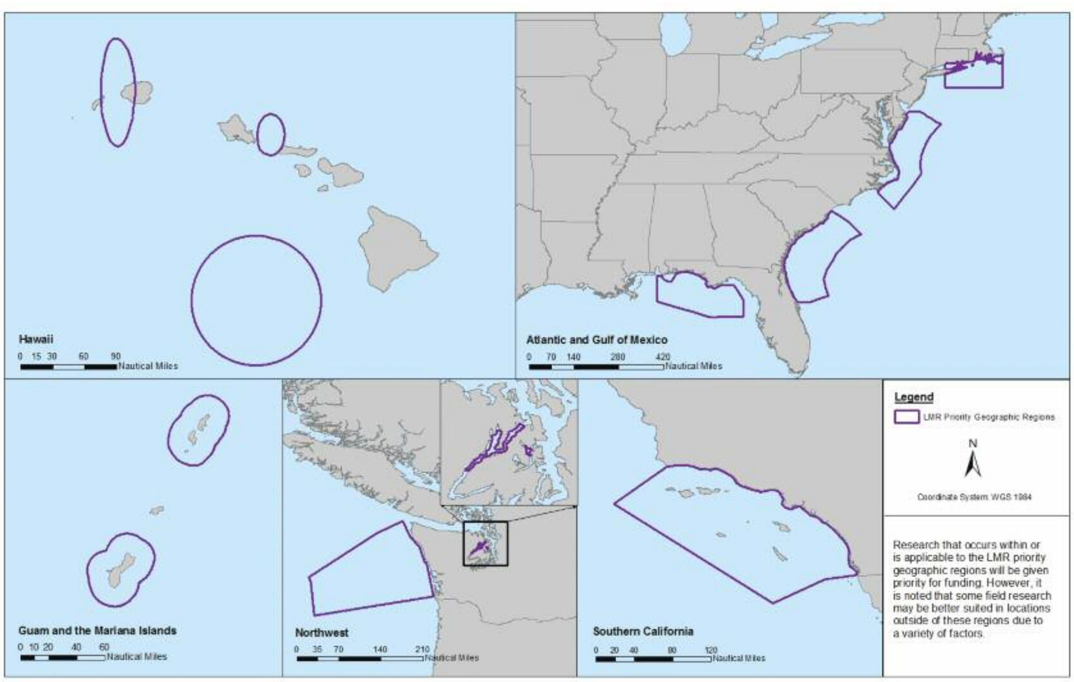
The LMR program is primarily interested in funding research that is applicable to geographic regions that are important to the U.S. Navy. The map below shows the LMR program priority geographic regions. It is important to note that the LMR program acknowledges that a variety of factors could lead to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



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.

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.

Annual Programmatic Review

The LMR program manager provides an annual programmatic review to the program's resource sponsor, OPNAV N45. The review includes information on the status of the overall program as well as ongoing projects. It notes accomplishments, needs, financial trends, budgeting issues and the outlook for the future. The review is an opportunity for the program manager and resource sponsor to confirm priorities and direction, make any mid-course corrections needed, and plan for the future to ensure that the program is advancing the Navy's military mission.

LMR Website

The program website 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. See the LMR website at navysustainability.dodlive.mil/lmr.

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

MCS1 Joseph M. Buliavac

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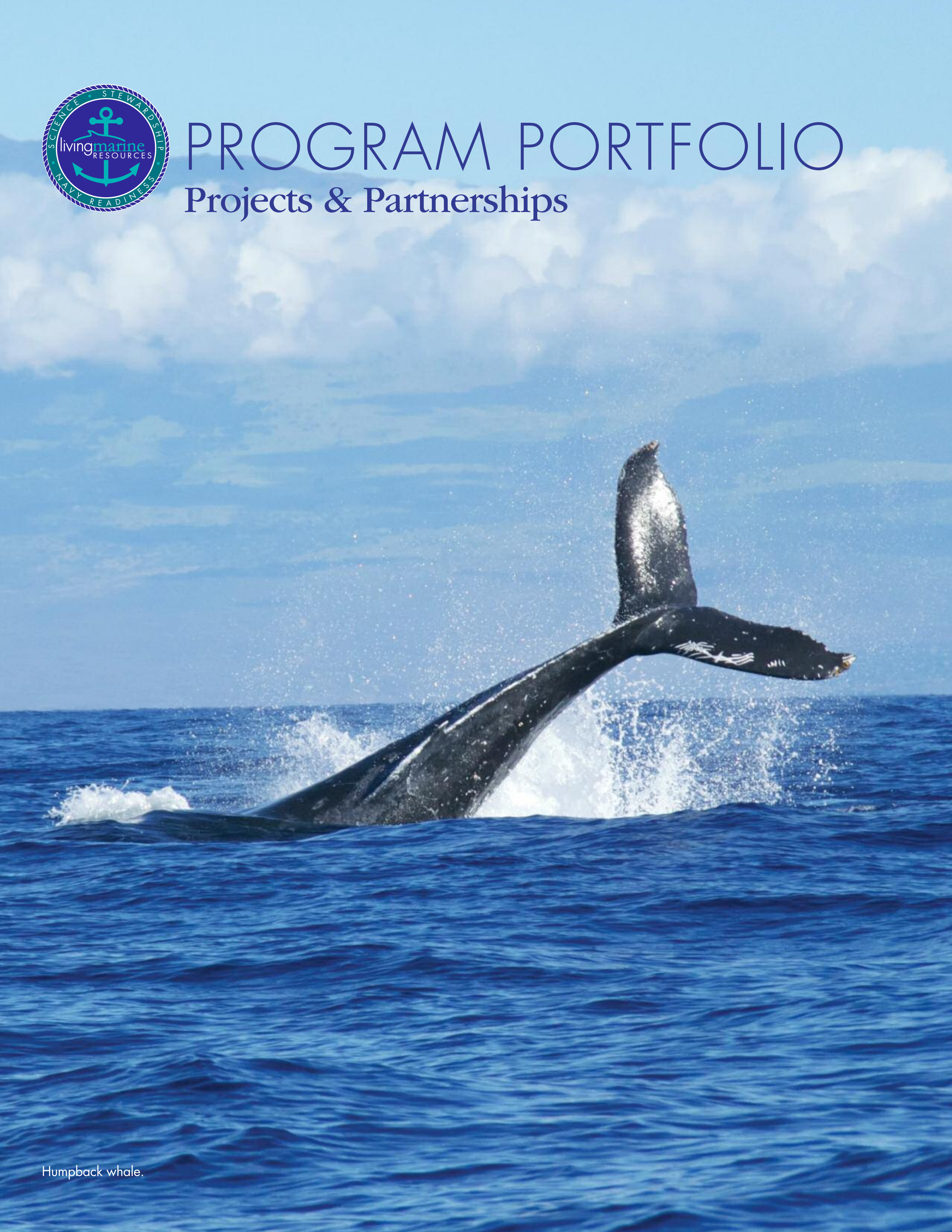
PROGRAM PORTFOLIO

Projects & Partnerships



Humpback whale.

Completed Projects

Four projects were completed during 2017. Results of each of the completed projects are available to Navy end users.

Demonstration of High-performance PAM Glider and Profiler Float

Principal Investigator: Haruyoshi Matsumoto
Project Status: Completed, Project 04

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.

The Seaglider floats are shown in the foreground, and the APEX floats are shown in the rear (upright position). All are equipped with the high performance passive acoustic module.

PROJECT

This project demonstrated the marine mammal monitoring capability of two commercially available autonomous PAM platforms, a glider and a float. The Seaglider from Kongsberg and an APEX-based float known as a QUEphone were assessed. Both the glider and the float are buoyancy-driven, deep-diving vehicles capable of descending to 1,000 meters (glider) and 2,000 meters (float). While gliders can be steered remotely, floats simply drift with the ocean current. The advantage of the float lies in its comparatively low cost, at approximately 25 percent of the cost of a glider. Although the two mobile platforms are acoustically quiet, there are differences in body shape, steering mechanism, water flow, pump and motor activities, and internal electronics noise. These differences, and their impact on system performance, were evaluated.

These two platforms were equipped with the Wideband Intelligent Sound Processor and Recorder (WISPR) system, which can record acoustic signals at 125 kHz sampling rate and 16-bit resolution while simultaneously running an automated marine mammal click detector. The system can run continuously for approximately 45 days, limited by data storage.

To provide for comparison, the mobile platforms were deployed in areas with bottom-moored high-frequency acoustic recording packages (HARP) and on Navy instrumented hydrophone ranges using the Marine Mammal Monitoring on Range (M3R) system. The two platforms were tested first in 2015 at the Quinault Training Range for a 13-day period. While the QUEphone float was quieter, the Seaglider detected more animal signals because the float was unable to stay in the target area. Unfortunately, the Navy instrumented hydrophone range was not recording during the testing period on this range, so no comparison was made.

The technology is now available for use by the Marine Species Monitoring program.

In 2016, the Seaglider and float were tested at the Southern California Offshore Range (SCORE) to compare to M3R detections. Although a malfunction of M3R data disks resulted in some data gaps, sufficient data were collected to proceed with the analysis for beaked whales, baleen whales and dolphins. The evaluation of detection performance indicated that when the Seaglider was moving fast, particularly as it descended, flow noise affected the performance of detecting baleen whales. Changing how the glider is ballasted could help to address flow noise. System electronics noises, however, did not appear to affect the detection performance on either platform. Overall, the detection ranges of both the Seaglider and QUEphone were about five kilometers on SCORE.

Subsequently, in 2017, both platforms were deployed during an ONR-funded project in an area off the coast of Santa Catalina Island with two HARPs. The HARP detections offered an opportunity to evaluate the mobile platform detections off of a Navy instrumented hydrophone range. Of the two mobile platforms, the mean number of detections from the QUEphone float was higher than the Seaglider, although during this deployment the float required more recovery and redeployment efforts than the glider, resulting in higher operational costs.

Each of the acoustic autonomous underwater vehicle (AUV) platforms offer an option for efficient, cost-effective marine mammal monitoring inside or outside of U.S. Navy instrumented hydrophone ranges or when poor weather conditions prohibit ship-based visual observation. As with any detection device, attention to the conditions within which they are deployed will influence performance. The instruments feature near real-time detection/classification capabilities and can relay information back to a control center onshore or a marine mammal observation team on a ship.

The final report, which includes performance metrics and use recommendations, was completed in 2017. The technology is now available for use by the Marine Species Monitoring program.

About the Principal Investigator

Haruyoshi Matsumoto is an adjunct faculty member and researcher at the College of Oceanic and Atmospheric Sciences, Oregon State University. Dr. Matsumoto also serves as principal investigator for the National Oceanic Atmospheric Administration's Pacific Marine Environmental Laboratory. He holds a Ph.D. in Ocean Engineering from the University of Hawaii.

Development of Automated Whistle and Click Detectors and Classifiers for Odontocete Species in the Pacific and Atlantic Oceans

Principal Investigators:
Julie Oswald and Tina Yack
Project Status: Completed, Project 05

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

This project developed a suite of fully automated whistle and click classifiers for odontocete species in three geographic locations—the northwest Atlantic Ocean, the temperate Pacific Ocean and the waters surrounding Hawaii. These classifiers, which combine information from whistles, clicks and the acoustic behavior of schools to identify the sounds produced by odontocete species, are helping to increase PAM data processing effectiveness.

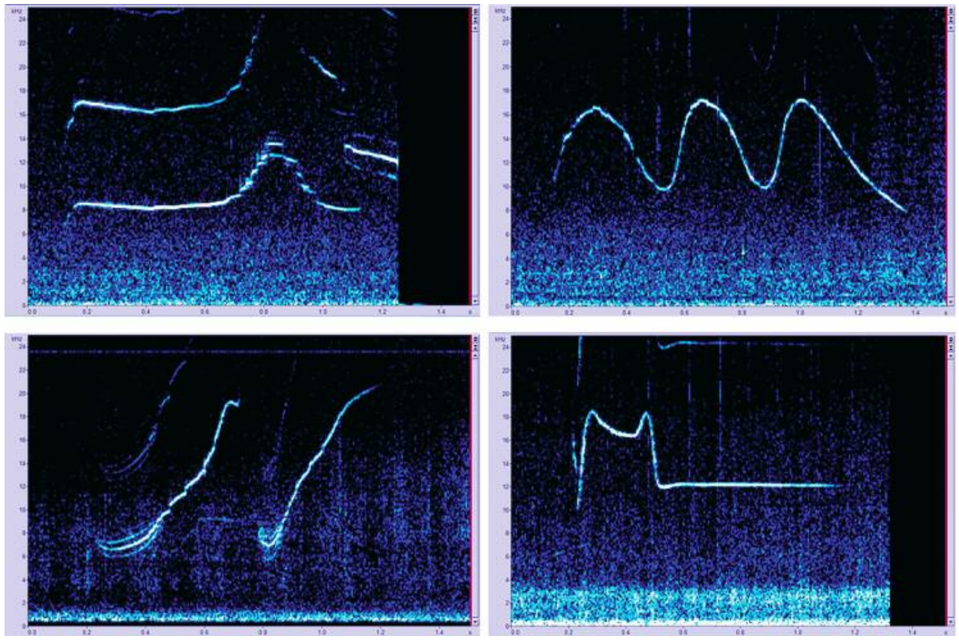
The variability inherent in many sounds produced by odontocetes has made it difficult to automatically detect and classify them. Sounds produced by odontocetes (particularly dolphin species) can be grouped into one of two broad categories—whistles and pulsed sounds (e.g., clicks). Previously, separate whistle and click classifiers have been developed for specific dolphin species. However, not all species produce whistles, or they may only produce whistles or clicks in specific behavioral contexts.

In this project the researchers combined information from different types of sounds to provide more power for identifying species than trying to classify based on only one sound type at a time. Not only do these automated classifiers include information from both whistles and clicks, they also incorporate other contextual information (e.g., geographic location, number of whistles, number of clicks, ratios of whistle to clicks, overlap among sounds, etc.) to advance the science of automated classification.

To make the classifiers more available and to help passive acoustic data analysts, the classifiers have been incorporated into passive acoustic data processing programs. These classifiers first were incorporated into an existing whistle classifier software called Real-time Odontocete Call Classification Algorithm (ROCCA). ROCCA is available as a module in the marine mammal passive acoustic data processing software program called PAMGuard. The classifiers now have also been made available for use in another widely used software package called Ishmael. Both of these software packages are freely available to all users.

> These classifiers…are helping to increase PAM data processing effectiveness.

This project was co-funded by the ONR Marine Mammals and Biology program. Of the three geographic classifiers, two were funded by ONR (the Hawaiian Islands and the northwestern Atlantic Ocean) and one was funded by LMR (temperate Pacific Ocean). ONR



Whistles produced by striped dolphins. These whistles illustrate the high within-species variability in whistle structure that exists in most delphinids.

funding also supported three manuscripts—one examining geographic variation in whistles, one examining geographic variation in clicks and one describing the classification approach and results.

Combining whistle, click and context variables to produce a final classification provides an important tool for efficiently and automatically processing the large data sets generated during PAM projects. When classification results from the whistle and click classifiers were combined with behavior and location variables to train and test the encounter classifiers, at least 80 percent of encounters were correctly classified for each geographic region. This improves the Navy's ability to characterize the presence and abundance of odontocetes, by species, within training and testing areas and reduces costs of manual reviews. The final report was completed in 2017 and the classifiers are now available for use by the Marine Species Monitoring program. The classifiers, user manuals and help files are available via the PAMGuard and Ishmael websites.

About the Principal Investigators

Julie Oswald was vice president and senior scientist at Bio-Waves, Inc. for six years. She currently is a Marie Curie Fellow at the University of St Andrews in Scotland. She participates in analyzing bioacoustic data, developing tools for passive acoustic monitoring, and providing assessments of the effects of noise on the marine environment. Dr. Oswald has a Ph.D. in Oceanography from Scripps Institution of Oceanography.

Tina Yack is currently the president and senior scientist at EcoSound Bioacoustics, LLC. She works in development and testing of towed hydrophone array hardware and passive acoustic monitoring and analysis software. She has expertise with Generalized Additive Modeling techniques to model cetacean distribution and habitat preferences using passive acoustic data, distance sampling methods for estimating acoustic-based density estimation in marine mammals, GIS services, and noise monitoring and mitigation. Dr. Yack has a Ph.D. in Ecology from the University of California—Davis.

Primary Audiograms of Hearing in Baleen Whales

Principal Investigator: Darlene Ketten
Project Status: Completed, Project 11

NEED

N-0012-13 Hearing and Auditory System Information for Hearing-based Risk Criteria

The Navy and NMFS rely heavily on hearing-based risk threshold criteria for assessing impacts from sound producing activities. Current gaps in understanding of these metrics have produced risk threshold criteria that are likely to be overly conservative. Few data, even for basic audiometry, are available for ESA-listed marine mammals, birds, fishes, or invertebrates. Many species are rare or difficult to keep in captivity, such as beaked whales and baleen whales, in which case modeling from anatomy or a capability to quickly test stranded animals (e.g. AEP methods) might be necessary. 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

Toothed whales have disproportionately large brains and can be readily tested by AEP methods, however baleen whales have exceptionally small brains for their body size and their AEP signals cannot be detected with current technology. For baleen whales, modeling from anatomy provides an important alternative method. This project pursued this alternative approach (modeling from anatomy) to determining hearing that is especially useful when other options (e.g. direct measurement) are not available. The overall goal of this work was to produce a composite model audiogram (a graphic representation of hearing ability) depicting the thresholds and hearing frequencies in these animals.

In order to produce composite audiograms, it is necessary to collect the following data: anatomical measurements of the ear from computerized tomography (CT) scans and histology, physical property measurements of the middle and inner ear, and finite element modeling (FEM) simulation data. Anatomical measurements of the inner ear membranes and nerves provide a map of what frequencies a species can hear: total hearing range, the high and low functional hearing limits, and the frequencies of greatest sensitivity and which frequencies produce peak noise impacts. The physical property measurements of the middle ear provide low frequency roll-off/slope and cut-off frequency, as well as the peak sensitivity spectra that determine the shape of the audiogram. The FEM simulation data provides the middle ear transfer function, which gives the relative sensitivity across the place frequency map, or the shape of the audiogram curve.

This work provided the first evidence of composite key features of hearing for any baleen whale...

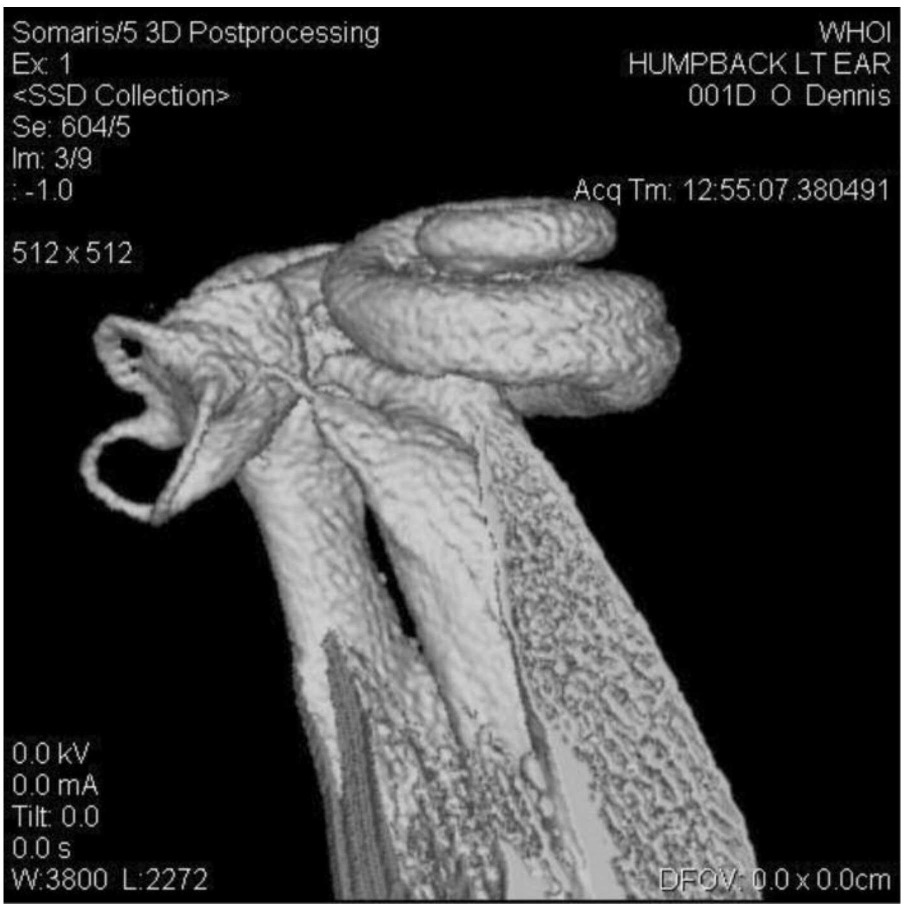
This work has been a long-term effort with previous funding from the ONR MMB program. Work completed under ONR funding focused on analysis of minke whale ears and the results for the minke whale middle ear modeling were previously published in the *Journal of Acoustical Society of America* (JASA) (Tubelli et al. 2012). The LMR program funded work was focused on analysis of the humpback whale ears, which built off of the previously completed minke whale work. The team was able to obtain model and experimental results

COMPLETED PROJECTS

for the middle ear transfer function (METF), which dictates the transmission of acoustic energy from the external ear to the cochlea for humpback whales. This work provided the first evidence of composite key features of hearing for any baleen whale, which include the low frequency roll-off slope, the low frequency cut-off, peak spectra and estimates of best frequency range based on two different stimulus locations. Results have been summarized in a manuscript that is currently under review with JASA. These results will be available for use in the Navy's Phase IV acoustic impact analysis.

About the Principal Investigator

Darlene Ketten is chief scientist of the Marine Imaging Facility of Woods Hole Oceanographic Institution. Dr. Ketten holds an M.S. degree in Biological Oceanography from Massachusetts Institute of Technology and a Ph.D. in Neuroethology and Experimental Radiology from The John Hopkins Medical Institutions.



3D reconstruction from CT scans of the inner ear of a humpback whale. The large spiral is the cochlea which contains the resonating membranes and nerves of the inner ear. The small canals on the left are the vestibular system which controls balance and detects gravity and acceleration. The large "stalk" extending from the spirals is the VIIIth or auditory nerve. Baleen whales have the largest number of nerve cells and nerve fibers devoted to hearing of all animals.

D. Ketten, WHOI

Behavioral Audiometry in Multiple Killer Whales

Principal Investigator: Brian Branstetter
Project Status: Completed, Project 14

NEED

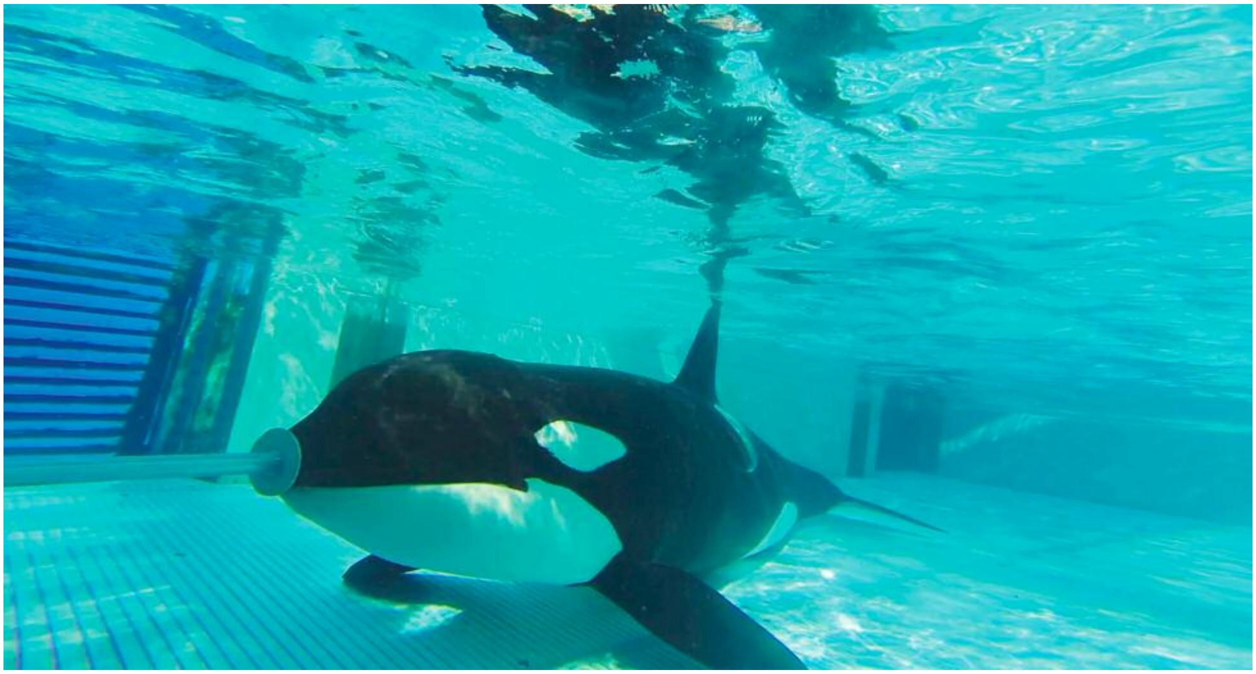
N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

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 measure hearing across a broad spectrum of ages, genders, and states of health in a variety of cetacean and pinniped species to better characterize population level hearing characteristics. 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

One species with a notably widespread distribution and high potential to be exposed to a range of anthropogenic sounds is the killer whale (*Orcinus orca*). This project gathered demographic hearing data from killer whales by measuring behavioral audiograms from eight individuals that varied in age from 12 to 52 years. The eight individuals included five males and three females.

Prior to this effort, knowledge about killer whale hearing was based upon audiograms collected in the 1970s and 1990s, from only three killer whales. The whales previously tested were two adult females and one subadult male with apparent high-frequency hearing loss in the male. All three killer whales had best sensitivity between 15 kHz and 20 kHz, with behavioral hearing thresholds significantly lower than any odontocete tested to date (e.g., 30 dB re 1 µPa), suggesting this species might be more sensitive to acoustic disturbance than other species. Not only did those results require replication and validation, the data were too limited to provide any insight into individual differences or demographic variability (e.g., age and gender) in hearing capabilities that have been demonstrated in other odontocete species.



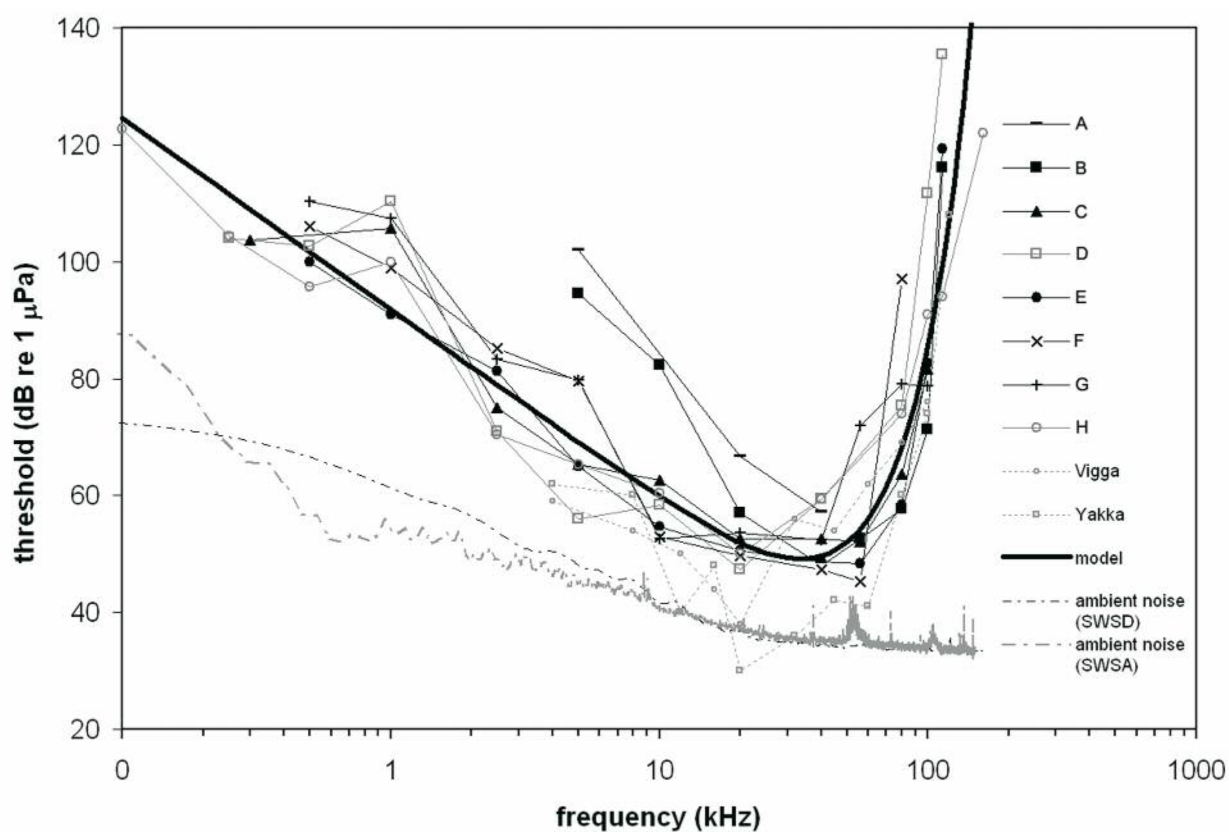
A killer whale positioned on a stationing device while participating in a psychophysical hearing test.

COMPLETED PROJECTS

In this project, audiograms were measured by conducting behavioral hearing tests using well-established psychoacoustic methods that are regularly employed by the National Marine Mammal Foundation (NMMF) for the testing of hearing in dolphins. Behavioral hearing tests require trained animals and are considered to be the "gold standard" of hearing tests, leading to the most accurate audiometric measurements. This project was a follow-on to a 2014 cooperative project between NMMF, Sea World San Diego and U.S. Fleet Forces Command. Testing took place at Sea World San Antonio and Sea World San Diego.

The project team collected the first demographic hearing data from killer whales to understand how potential acoustic impacts might vary within a mixed population of animals (across age and gender). This research has expanded our understanding of killer whale hearing capabilities by measuring thresholds across a broad range of frequencies between 100 Hz and 160 kHz for eight animals. Previously measured low thresholds at 20 kHz were not replicated in any individual. Hearing in the killer whales was generally similar to other delphinids, with lowest threshold (49 dB re 1 µPa) at

The final results were incorporated into the Navy's Phase III acoustic criteria update.



Audiograms of individual killer whales. Solid black lines represent animals from the current study while dashed lines represent animals from Szymanski et al. (1999). The "model" data is a composite audiogram representing the species. Average ambient noise values are in dB re 1 µPa2 / Hz.

approximately 34 kHz, good hearing (i.e., within 20 dB of best sensitivity) from approximately 5-81 kHz, and low- and high-frequency hearing cutoffs (> 100 dB re μPa) of 600 Hz and 114 kHz, respectively. The killer whale composite audiogram was compared with composite audiograms from three other odontocete species (bottlenose dolphin, harbor porpoise and beluga whale) for which behavioral audiograms were also available. Average mass for each species was found to be correlated with frequency of best sensitivity and high-frequency cut-off. In general, smaller animals hear higher frequencies better than larger animals. These data may be useful in predicting hearing abilities of other odontocete species for which data are sparse or lacking.

The final results were incorporated into the Navy's Phase III acoustic risk threshold criteria update and were published in the *Journal of the Acoustical Society of America* in 2017. See the publications list on pages 90-91 for the citation.

About the Principal Investigator

Brian Branstetter is a research scientist at the National Marine Mammal Foundation. Dr. Branstetter's research interests are conservation-based and focus on marine mammal psychoacoustics and cognition, echolocation, auditory masking, whistle production and perception, and vigilance in dolphins. He earned his Ph.D. from the University of Hawaii, Manoa.

MCS2 Eli K. Buguey

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.

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, seven ongoing projects and three new projects started in 2017.

Ongoing

1. Project 2 Southern California Behavioral Response Study
2. Project 20 Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises

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

3. Project 22 Hearing and Estimated Acoustic Impacts in Three Species of Auk: Implications for the Marbled Murrelet
4. Project 23 Cuvier's Beaked Whale and Fin Whale Behavior During Military Sonar Operations: Using Medium-term Tag Technology to Develop Empirical Risk Functions
5. Project 24 Frequency-dependent Growth and Recovery of TTS in Bottlenose Dolphins
6. Project 25 A Blainville's Beaked Whale Behavioral Risk Function for Hawaiian Populations
7. Project 26 The Effects of Underwater Explosions on Fish

New Starts

1. Project 29 3S3: Behavioral Responses of Cetaceans to Naval Sonar
2. Project 30 Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar
3. Project 32 Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

Ongoing Projects

The Southern California Behavioral Response Study

Principal Investigators:
Brandon Southall and John Calambokidis
Project Status: Ongoing, 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) is providing results on cetacean (e.g., whales and dolphins) responses to simulated and operational Navy sonar. The overall objective is to increase understanding of marine mammal behavior and reactions to sound, and 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.

Field teams from multiple institutions included 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 occurred during summer and fall months in various coastal and offshore areas spanning the Southern California Bight from 2010 through 2016. High-resolution movement and acoustic archival tags were deployed on focal animals using well-established safety and mitigation protocols authorized under research permits. These tag deployments comprise one of the largest high-resolution data sets ever collected in marine

Tagged blue whale, with the BRS research vessel, *Truth*, in the background.
John Calambokidis, NMFS permit 16111

mammals with nearly 200 tag deployments on 10 federally protected marine mammal species. Both underwater acoustical monitoring methods and visual observers were employed to monitor focal and other animals and to meet research permit mitigation requirements.

> Data from this project are used in the Navy's impact assessment to estimate the number of times animals may behaviorally respond to acoustic sources.

Controlled exposure experiments (CEEs) were then conducted within well-defined protocols using sounds of several 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. All work was conducted within the terms of applicable federal and state research permit requirements. Considerable effort has been made to transparently communicate methods and results in scientific publications, technical meetings, and to the general public in a variety of ways.

Over 20 peer-reviewed publications have already been published from the SOCAL-BRS project thus far. A final analysis phase is underway and was the project's focus in 2017. At least eight additional publications, mostly relating to behavioral response, are forthcoming. These will include key data from later phases of field efforts in which CEEs of marine mammals exposed to operational Navy MFAS sources were conducted. These data provide unprecedented measurements of marine mammals responding to Navy MFAS within experimental conditions in which key contextual and exposure conditions were known and controlled. Work completed in 2017 focused on

1. Additional analyses of behavioral responses of blue whales, fin whales and Risso's dolphins to simulated MFAS
2. Comparative analyses of responses to simulated and real MFAS at variable source-animal ranges for multiple species
3. Publications on baseline movement and foraging behavior on various time scales.

While these ongoing analyses and publications will continue to provide insight into the nature of behavioral response type and probability in the protected marine mammal species studied, a number of general conclusions are evident. These are based on both the published results and in-progress analyses resulting largely from LMR-supported effort in 2017. Key findings include

1. Behavioral responses to MFAS exposure varied by species. Beaked whales demonstrated the clearest and strongest responses, whereas other species had weaker and more variable responses depending on conditions.
2. Responses within species appear to differ based on some combination of source type and physical range. Exposure to louder full-scale MFAS sources (53-C) at greater ranges is less likely to result in comparable behavioral changes than exposure to similar received levels from simulated MFAS sources at closer ranges. Some relatively strong responses in a limited number of helicopter-dipping sonars appeared more similar to earlier simulated MFAS CEEs.

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

3. For blue whales, for which a relatively large sample size during CEEs was achieved (n=57), responses are strongly dependent on behavioral context with deep feeding animals more likely to respond than shallow feeding or non-feeding animals. Including information on prey provided key insights in terms of detecting this response, given that whales were changing behavior simultaneously in relation to both noise exposure and environmental parameters.

4. Experimental approaches using high-resolution measurements from SOCAL-BRS provide key quantitative data with novel insights into factors such as behavioral state, spatial proximity and environmental variations that have as much or more bearing on response probability as simple received sound level. These findings have major implications for effecively estimating potential impacts and responsible mitigation. They also inform subsequent research and monitoring efforts taking place using coarser methods over longer time scales.

The SOCAL-BRS is continuing to work directly with the Navy to transfer these findings into their environmental impact assessments and permitting processes. Specifically, data from this project are used in the Navy's impact assessments to estimate the number of times animals may behaviorally respond to acoustic sources.

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)

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.

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.

All data for both behavioral response studies were collected by the end of 2016, and phase 1 analyses have been submitted for publication in 2017. During the first phase 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. At the 96 percent duty cycle, one of the two animals showed increased respiration and moved away from the transducer. Analyses of phase 2 data are continuing, with reports expected in 2018.

Sub-adult male porpoise 06 ingesting a herring, his reward during a behavioral hearing test in one of the temporary threshold shift studies.
Léonie Huijser, SEAMARCO

The TTS study consists of three phases:

1. Establish the audiograms of the two study animals. Because the animals arrived at SEAMARCO 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.

The first two phases of the TTS study have been completed and results published in the *Journal of the Acoustical Society of America*. These publications include audiograms for the two animals and results of TTS phase 2. Results 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 during 2017. Data have been collected for three of the five frequency levels planned.

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 (Sea Mammal Research Company, Inc.) 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 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. Data collection efforts will include in-air AEP tests, in-air behavioral audiometry tests and underwater behavioral audiometry tests. This will allow comparison of AEP and behavioral audiometric methods, as well as comparison of in-air and underwater measurements. The resulting audiograms will provide the data and training foundation for a temporary threshold shift (TTS) response feasibility study.

The Navy needs data to improve impact assessments and validate associated mitigation zones related to birds.

During 2017 the project team secured all necessary permits, set-up its field test station and calibrated hearing-test equipment at the study site in Iceland. They collected AEP data from puffins and common murres, which provided preliminary response thresholds. The field-based AEP tests—widely used, non-invasive, rapid hearing test methods—involve measuring small voltages that the brain and auditory nervous system generate in response to sound.

Subsequent work will include lab-based behavioral audiometric tests that will involve animals trained to perform a specific behavior in response to sound. The tests will

Common guillemots (*Uria aalge*) at their colony in Langanes, Iceland. This is one of the species of Alcidae that Mooney and colleagues may examine in hearing studies.
Marianne Rasmussen

begin with the in-air behavioral audiometric tests, followed by the underwater behavioral audiometric tests. In-air behavioral audiometric tests will begin during 2018.

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 maybe 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.

An Atlantic puffin (*Fratercula arctica*) at a colony in Northeastern Iceland.
Marianne Rasmussen

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 involving the use of 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 for collection of animal behavioral data without needing to schedule with the Navy platforms (e.g., ships, helicopters), allowing for a larger sample of real-world exposures to be recorded. The team will use 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.

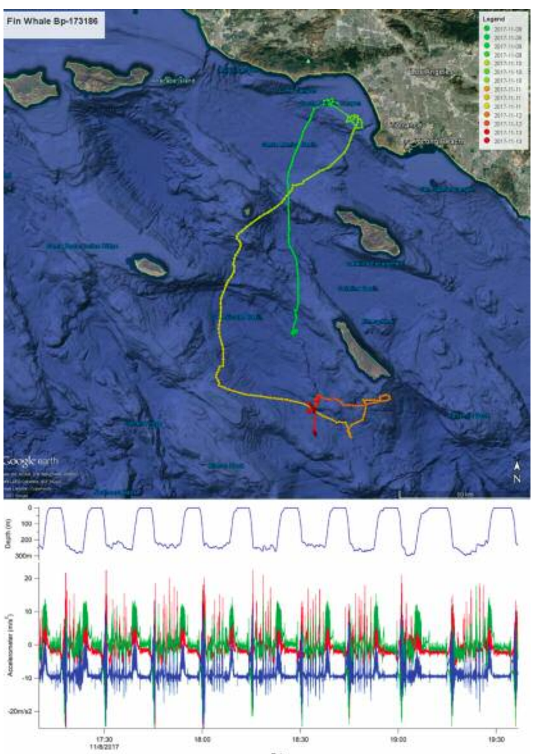
Large sample sizes over broad temporal and spatial scales around real exercises will yield results that are directly applicable to risk function development for Navy compliance efforts.

The primary tag the project currently is using is a new version of the Wildlife Computers/Andrews Whale Lander tag, referred to as Lander2 tag. This tag includes Fastloc Global Positioning System (GPS) and a 3-axis accelerometer that provide detailed location and movement data. The tags also include standard 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 also has refined the deployment and attachment mechanisms to increase deployment duration. The team hopes to incorporate acoustic recording capabilities to the tag in 2018.

During 2017, the project team lab-tested new tag deployment mechanisms before beginning field testing.

One 10-day survey effort was completed as planned, resulting in 45 sightings of 11 marine mammal species and one tag deployment on a fin whale, which was exposed to dipping helicopter MFA sonar after tagging. This first effort was an opportunity to field-test the tags, the deployment mechanism, and to refine a combined visual and acoustic surveying technique that uses M3R real-time acoustic detections to direct the tagging boat to target species. Results from the field-test effort are being incorporated into subsequent survey plans.

In the analysis phase, the team will 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. This comprehensive dataset 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.



Preliminary data from the fin whale tag deployed during the 2017 field effort. The top panel is the GPS track of the whale, with the track color changing over time. The bottom panel is 2 hours of dive trace with depth in blue at the top, and the 3-axis accelerometer data displayed at the bottom (one color for each axis).

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

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.

During 2017 the project team conducted initial behavioral training of the bottlenose dolphins necessary to measure hearing based on behavioral response. The team also completed baseline measurements to confirm that the animals being tested have hearing within normal range. Team members also coordinated with members of another LMR project, Behavioral

Bottlenose dophin.

Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises (project 20), to develop consistent exposure protocols. This will support comparability of resulting data.

High-frequency TTS data will be collected during 2018 and low- and mid-frequency data collected during 2019.

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 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 Investigator: David Moretti
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.

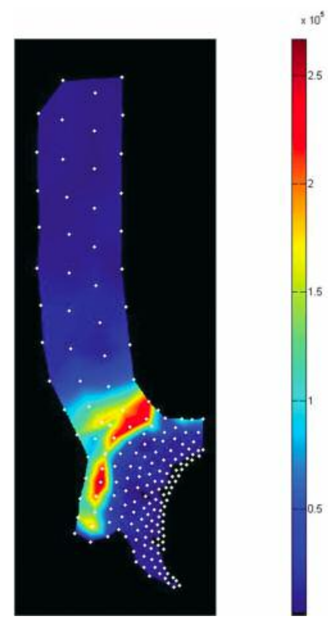
PROJECT

Currently, the Navy's acoustic impact assessments use behavioral risk functions 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.

[This project] will provide a direct comparison of risk functions derived for the same species, exposed to the same source types, in different ocean basins.

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. Animal densities and hydrophone spacing at PMRF are just two of differences to be accounted for within the modeling.

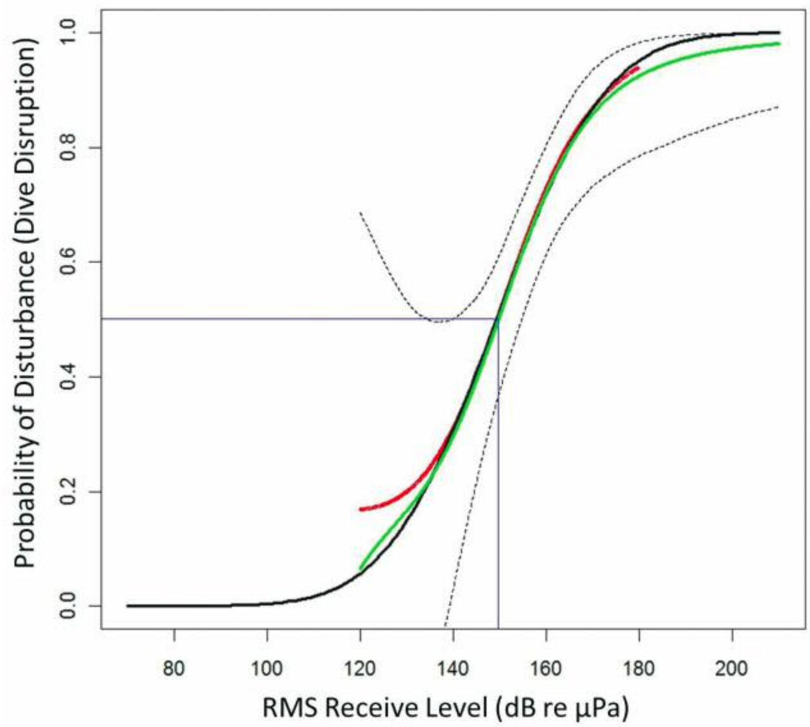
In 2017, the team began by analyzing existing data from a Submarine Command Course (SCC) training event previously conducted on PMRF to detect presence of Blaineville's beaked whale groups, detect pres-



Distribution of Md Click Counts on PMRF, July 2012.

ence of sonar signals, and estimate received levels per group. These data will then be used to determine an intial fit of the model and any needed adjustments. In addition to the initial data extraction and model fit work, the team made progress on calibrating a portion of the hydrophones on the range. Calibration of the remaining hydrophones will be completed in 2018.

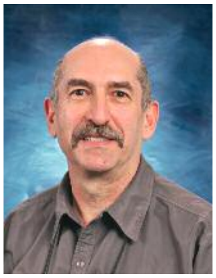
The behavioral risk function developed under this project will be based on real Navy sonar source data over a broad scale and will include a large number (more than 100) of beaked whale dive starts from multiple groups to provide insight into levels at which these animals react in the Hawaii environment.



The AUTEC Blainville's beaked whale behavioral risk function that provides the probability of disturbance (Drms) as a function of sonar RLrms. The GAM fit to the recorded data is shown in red with the bootstrap mean shown by the green with the point-wise 95% confidence limits indicated by dotted lines from the bootstrap. The parametric GLM approximation is shown in black. There is a 0.5 probability of disturbance at a RLrms of 149.8 dB; this is indicated in blue.

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.

Elizabeth Henderson is a bioacoustic scientist with the Navy Marine Mammal program at the Space and Naval Warfare Systems Center. She focuses on bioacoustic and noise impact analyses for environmental compliance.

The Effects of Underwater Explosions on Fish

Principal Investigator: Peter Dahl
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 will analyze 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) will be examined using quantified necropsy techniques. Careful attention has been focused on ensuring a biostatically valid design and sample size. This approach will provide a broader and more comprehensive understanding of potential effects and dose-response relationships.

Measuring underwater explosives on the Pu'uloa naval test range.
Lee H. Shannon

> 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.

During 2017, in addition to refining the experimental design, the team evaluated the fish cages to be used during the experiment. This included building the fish cages, as well as field testing deployment and recovery methods. The project continued work on experimental protocols and coordination with the relevant Navy commands. Navy Explosive Ordnance Disposal technicians are important participants for the field experiments to ensure safe and appropriate detonations that are also carefully coordinated with experimental design.

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 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 primary focus on underwater sound. Dr. Dahl earned his Ph.D. from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1989.

Key collaborators include Keith Jenkins from the Space and Naval Warfare Systems Center Pacific and Art Popper from the University of Maryland.

MCS Trey Fowler

New Start Projects

3S3: Behavioral Responses of Cetaceans to Naval Sonar

Principal Investigator: Frans-Peter Lam
Project Status: New start, 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 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 to the source 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).

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?

> This project is evaluating the potential effects of a relatively new type of sonar—continuously active sonar (CAS)…

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

The project employs 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.

For smaller, faster species like the pilot whale, a hand-held pole is used to deploy the DTAGs.
Rune Roland Hansen, permitted by the Norwegian Animal Research Authority (Mattilsynet), permit 2015/223222

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, conducted during late June to mid-July 2017, 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. Baseline data also were collected from pilot whales. Analysis of data will continue into 2018.

As currently planned, a Norwegian Navy frigate will be added to exposure experiments in 2019. This work will focus on using the frigate to transmit sonar at higher source levels, but achieve the same exposure levels at much longer distances. This will supplement the data set on the effect of range, and allow investigation into whether the effect of range is more important at relatively long distances. Planning and coordination will occur in 2018 to confirm the feasibility of this method.

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 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.

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

Principal Investigator: Stephanie Watwood
Project Status: New Start, 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 controlled exposure experiments (CEE) using sonar from two different platforms, each of which will be deployed at multiple, pre-defined distances from tagged animals. The effort is being coordinated with another LMR-funded project that is

> The results will allow the Navy to improve impact assessments…

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 (LMR project 23) is employing an opportunistic exposure (OE) approach, in which animals are tagged prior to Navy training activities in order to document the behavior of these two species before, during and after the actual Navy exercises. The data from the CEEs will augment the OE data. (For more detail on the OE project and the tags being used, see LMR project 23, page 38.)

The CEE 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 following table. Standard mitigation actions are conducted prior to all experiments, as outlined in the research permits.

Animal response data are collected from the same tags on the same animals

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

	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 (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.

that are tagged for the OEs. However, the data regarding sonar sources is collected in much finer detail for the CEEs, with information regarding time, distance and the sources themselves.

The monitoring tags being used by the teams are high-resolution, behavior recording tags deployed on Cuvier's beaked whales (*Ziphius cavirostris*) and ESA-listed fin whales (*Balaenoptera physalus*) on the Southern California Offshore Range (SCORE). The primary tag is a new version of the Wildlife Computers/Andrews Whale Lander tag, referred to as Lander2 tag. If it becomes available during the study timeframe, the team will use the SMRT (Sound and Motion Recording and Transmitting) tag, which will also provide acoustic data.

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.

Adding this CEE 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 CEE 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 Investigator: Colleen Reichmuth
Project Status: New Start, 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

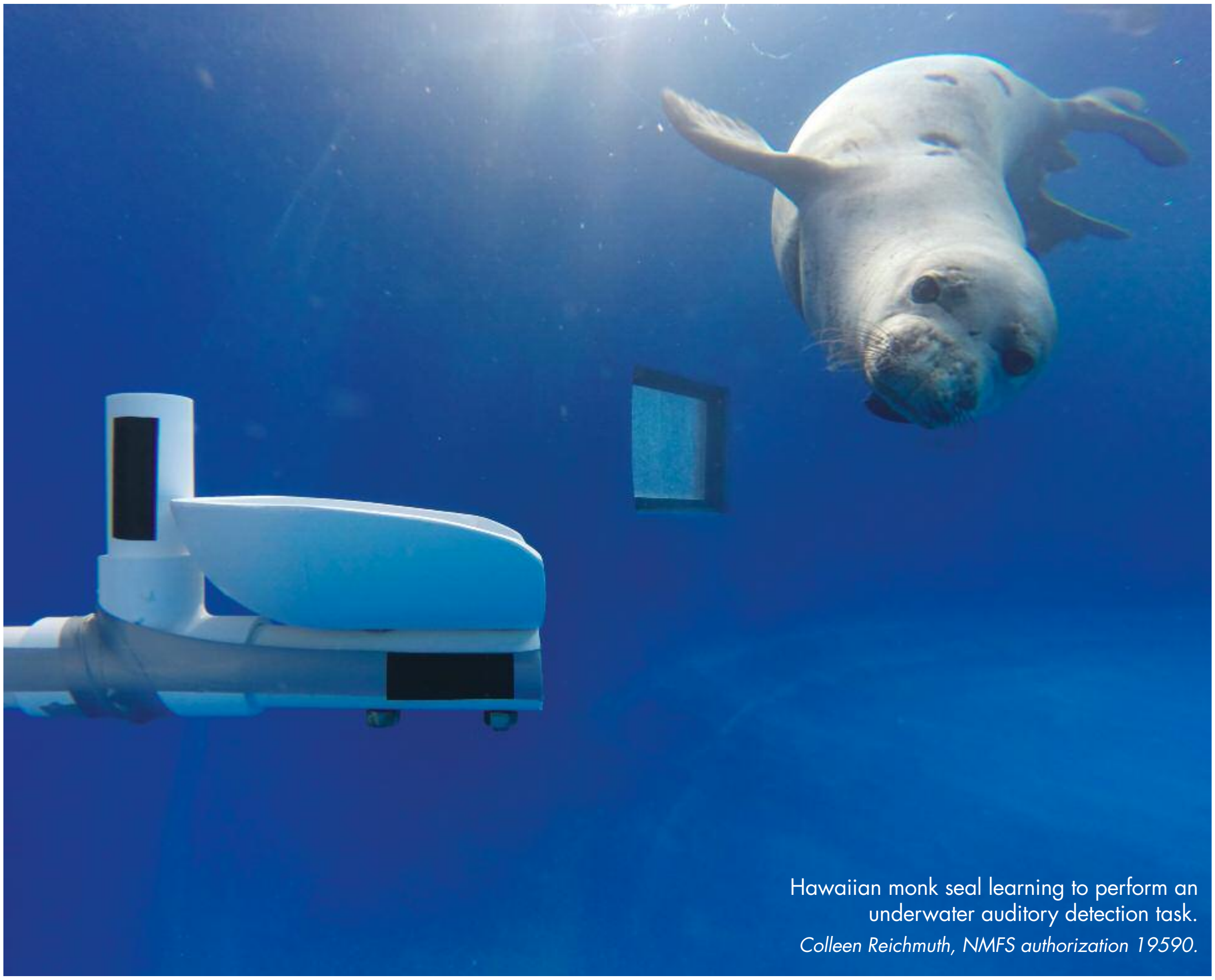
Navy training and testing activities occur in waters surrounding the Hawaiian Islands, with some in areas overlapping habitat for the ESA-listed Hawaiian monk seal (*Neomonachus schauinslandi*). However, there is little bioacoustic information regarding the monk seal, including information about hearing abilities and production of underwater sounds. This 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 underwater auditory sensitivity thresholds—across the full frequency range of hearing—for a specially trained adult male Hawaiian monk seal. The resulting data will be used to generate an underwater audiogram that will help to support impact assessments of the Hawaiian monk seal's sensitivity to sound.

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. The seal's hearing is being tested during auditory signal detection trials while diving in an acoustically calibrated pool. The seal is trained to report the presence of a tone by touching a target, and to withhold responding in the absence of the tone. During the test, the tone's amplitude (generally considered to be the sound level) is progressively varied from an easily detectible level to an undetectable level. This approach makes it possible to measure the minimum sound levels reliably detected by the seal at a range of frequencies.

The results will allow the Navy to improve impact assessments and 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. The resulting underwater hearing profile, or audiogram, will provide reliable information about the monk seal's ability to detect sounds that may be present in natural environments.



Hawaiian monk seal learning to perform an underwater auditory detection task.
Colleen Reichmuth, NMFS authorization 19590.

The results will 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 Investigator

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.

A key collaborator is Dr. Jillian Sills, 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.

INVESTMENT AREA 2.
DATA PROCESSING AND ANALYSIS TOOLS

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

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

The following section includes summaries of five projects—four ongoing projects and one new project started in 2017.

Ongoing

1. Project 3 Simple Performance-characterized Automatic Detection of Marine Mammal Sounds
2. Project 16 Passive Acoustic Density Estimation of Baleen Whales: Using Sonobuoys to Estimate Call-rate Correction Factors
3. Project 17 Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data
4. Project 19 DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas

New Start

1. Project 31 DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling


MSC3 Michael H. Lehman

Ongoing Projects

Simple Performance-characterized Automatic Detection of Marine Mammal Sounds

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

NEED

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

As 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 has focused on enhancing an existing bioacoustic software package (called Ishmael), improving the software interface and developing training for users to facilitate use of automatic signal detectors and classifiers. These changes to Ishmael will help technicians more efficiently detect and report marine mammal presence using acoustic data.

The Ishmael (Integrated System for Holistic Multi-channel Acoustic Exploration and Localization) program, is a popular bioacoustics software program that supports detection, classification and localization of marine mammals using acoustic signals. The program was originally developed by Dave Mellinger with funding from NOAA and ONR. It includes recording capability for real-time input, several methods for acoustic localization and automatic call recognition, and sound waveform and spectrogram displays.

Within Ishmael are marine mammal call detectors and classifiers, which can be tested against archived sound files of marine mammal calls. The archived sound files, publicly available at MobySound.org, include recordings of over 35 marine mammal species. The MobySound recordings have been annotated to indicate where (in time and frequency) each call occurs and what its signal-to-noise ratio is—information crucial to evaluating detector/classifier performance.

These changes to Ishmael will help technicians more efficiently detect and report marine mammal presence using acoustic data.

This project has focused on several changes to make Ishmael accessible to more users, while also expanding the program's capabilities. Progress to date includes improving the user interface (making it easier to use), as well as adding eight new species detectors, including ones of special interest to the Navy such as beaked, sperm and baleen whales. Performance information for each new detector is available. Some detectors, as appropriate, reflect specific geographic and temporal differences (e.g., mix of species in an area, call variations by area or over time, etc.). Detectors can be accessed online or downloaded. The program also now includes links to the programming platform, MATLAB®.

The project has completed extensive revisions to the Ishmael user's guide and produced an Ishmael tutorial for new users. A well-received stand-alone training

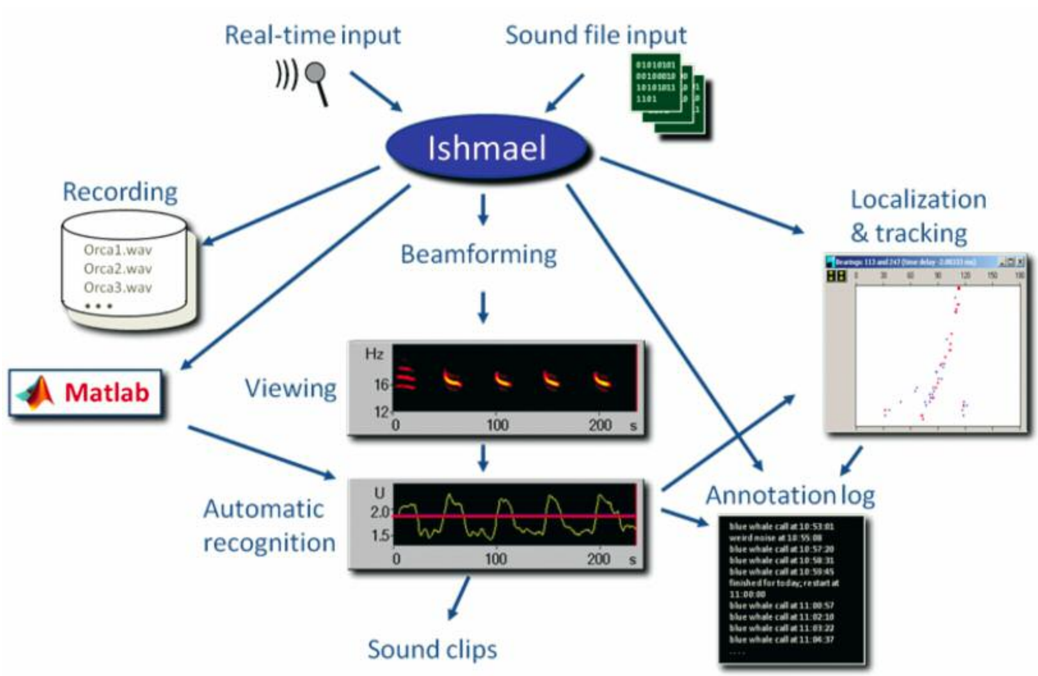
Map from the detector archive showing detectors that are currently available.
Dave Mellinger

workshop was held in 2017. Workshop attendees included Navy personnel, private (contractor) acoustic analysts, as well as regulators who are involved in the analysis of acoustic data. An additional training workshop is planned for 2018. Training materials also will be presented as a module in the Passive Acoustic Technology training course planned by Bio-Waves, Inc.

With these new modifications and improved training and support materials, a relatively naive user can sit down, choose what species to monitor and have the system provide detections and other performance measures for the selected species. 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.

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.



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.

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 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.

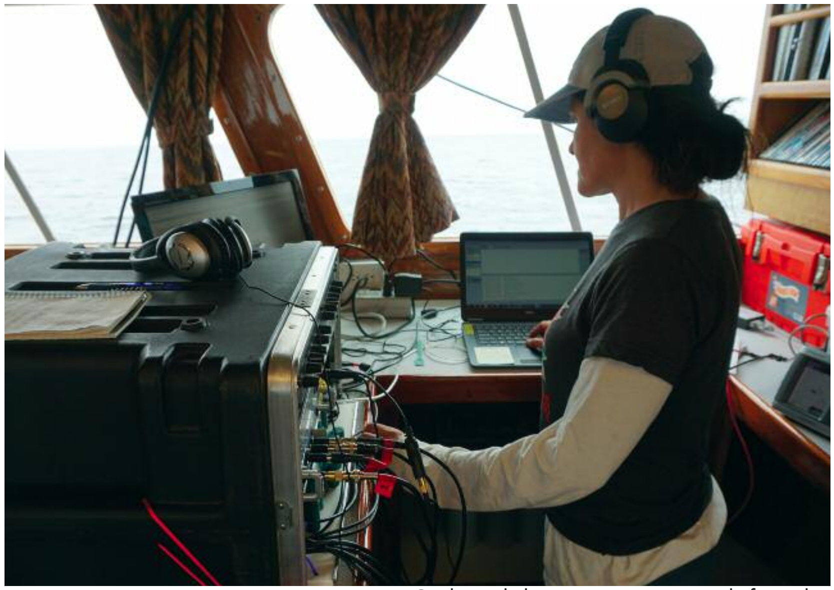
In order to estimate call density from sonobuoys, the team

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

In 2016, team members conducted playback experiments to examine factors related to sonobuoy calibration and bearing angle estimation of calls. During the experiment several sources of error were identified. Therefore, a specific protocol was developed with recommendations for sonobuoy deployment, calibration and drift calibration.

These efforts are providing new insights into methods for estimating density using PAM data.

Work during 2017 focused on analysis of existing data and identification of issues and suggested improvements. Methods to estimate bearing angles arising from using the directional low-frequency analysis and recording (DIFAR) software module in PAMGuard are prone to errors. An alternative approach was recently developed by Aaron Thode at Scripps Institution of Oceanography that may alleviate many of the problems associated with the current method of DIFAR bearing angle estimation. Preliminary analysis suggests that this alternative method will allow for simple examination of the background noise, improved detection and improved bearing angle estimation. Recommendations include incorporation of this approach into a future modification of the PAMGuard DIFAR software module.



On board ship, monitoring signals from the deployed sonobuoys.

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. The team developed recommended software modifications to help address these issues within PAMGuard.

Due to the large number of unexpected problems encountered, this project is serving as a 'proof of concept' for density estimation using sonobuoy data. However, the development work completed thus far can be used to improve analysis of sonobuoy data in general. The team is identifying potential solutions to problems, including suggested changes to data collection, acoustic software modification, and analytical approaches appropriate for working with arrays of sonobuoys. The final report is scheduled to be completed in 2018.

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

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.

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

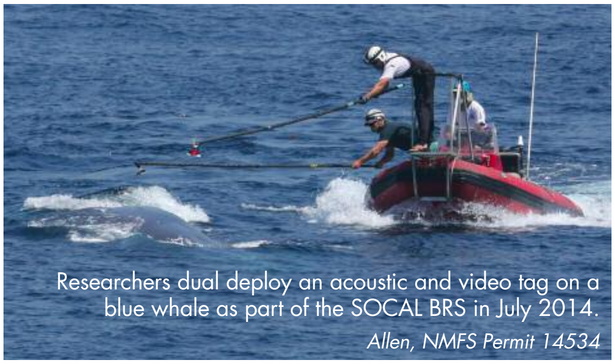
The Navy needs to be able to derive improved density estimates for species of concern using Passive Acoustic Monitoring (PAM) data collected at sites of high Navy interest. Density estimation from PAM data requires a high level of data collection planning, metadata collection and external calibration 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 project is developing spatially and temporally explicit density estimates for blue and fin whales in the Southern California (SOCAL) range to provide data necessary for the Navy's acoustic impact assessments.

In order to estimate density from passive acoustic data, knowledge of call rates of the animals is needed. To determine caller abundance, call detection range and the probability of call detection within that range will be estimated using passive acoustic data. Acoustic propagation models will be developed to estimate call densities and detection ranges to be applied to the animal density calculations.

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-



Researchers dual deploy an acoustic and video tag on a blue whale as part of the SOCAL BRS in July 2014.
Allen, NMFS Permit 14534

term tag data provide more information on variations between night and day behaviors influencing calls.

Work during 2017 included field surveys to collect new data, with tags deployed on two blue whales and one fin whale. Progress was made on analyzing call rates for blue whales, but the sample size for fin whales is currently still too low to support call rate estimation. Work in 2018 will include a second field effort and development of call rate models and density estimates for blue whales.

> This project is developing… explicit density estimates for blue and fin whales… for the Navy's acoustic impact assessments.

About the Principal Investigator

Ana Širović is an assistant research oceanographer at the Scripps Institution of Oceanography. Her research focus is on the use of new, non-lethal methodologies to promote a better understanding of endangered marine species. Dr. Širović earned her Ph.D. in Oceanography from the University of California San Diego.

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

Principal Investigator: Len Thomas
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 passive acoustic density estimation that can be used across a range of species, environments and temporal scales. The project team will deploy retrievable, bottom-mounted passive acoustic sensors 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 57), 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 SOCAL Behavioral Response Study and the Marine Mammal Monitoring on Ranges (M3R) projects—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. A test deployment of the passive acoustic recorder array is planned for 2018. After results from the test deployment are analyzed and any necessary adjustments made, the full array will be deployed.

> **The project will produce density estimates for Cuvier's beaked whales and fin whales in SOCAL…**

The project will produce density estimates for Cuvier's beaked whales and fin whales in SOCAL and include associated animal distribution maps that combine data from both instrumented and non-instrumented ranges.

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 Colombia.

New Start Project

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

Principal Investigator: Len Thomas
Project Status: New Start, Project 31

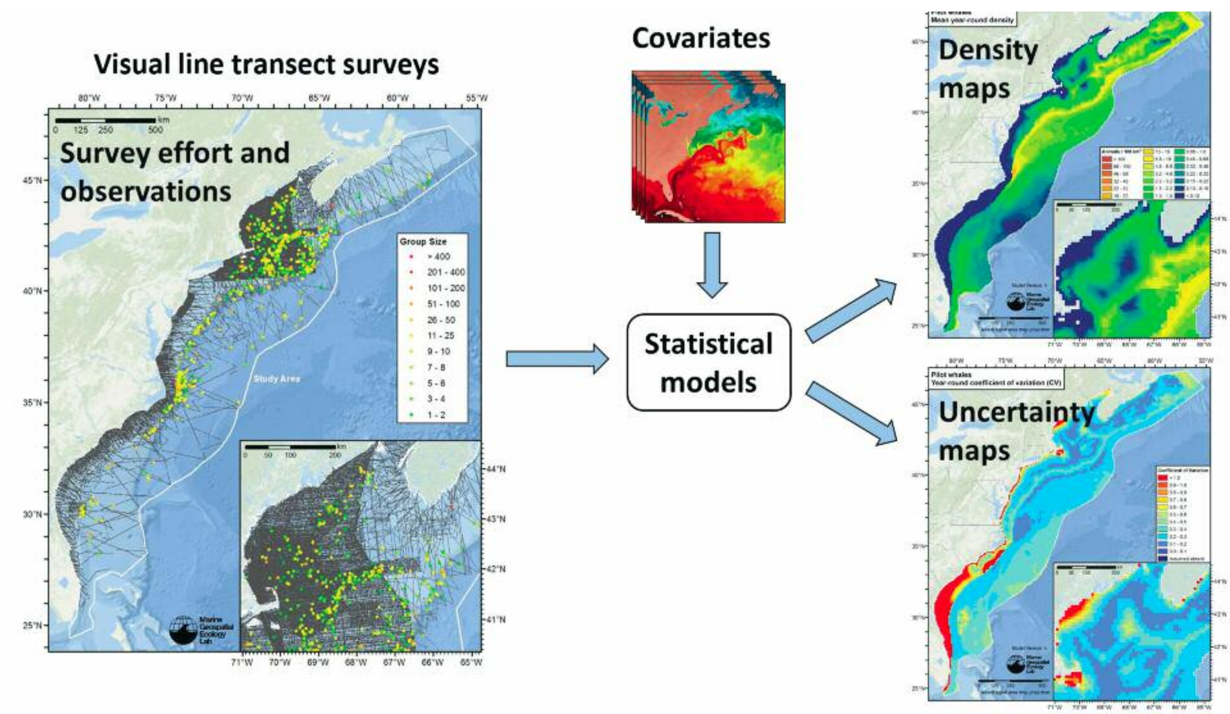
NEED

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), describes animal population density as a function of spatially and, in some cases, temporally referenced physiographic, physical oceanographic and biological variables. Examples of such variables can include bathymetry, distance to ocean fronts, sea surface temperature and chlorophyll (variables can vary based on species and locations). Many approaches have been proposed and applied to density surface models used by the Navy and others, which could affect the reliability of model estimates. This is partly due to the variety



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

> **The project will lead to a substantial improvement in the reliability of the Navy's impact assessments…**

of datasets available for each geographical area of interest to the Navy. Improvements to density estimates, including an increased understanding of the uncertainty inherent in combining multiple datasets, are needed to refine the Navy's quantitative impact assessments.

In this project, a working group of modeling experts is focused on developing and implementing innovative approaches to improve spatial modeling methods used to characterize seasonal abundance and distribution of marine species. The group will address different data sources and available analytical methods for estimating species population and distributions. In addition to transect survey data (a more traditional approach to collecting data on number of animals in an area), two other data sources for discussion will include acoustic monitoring and unmanned aerial vehicles. Goals for the group 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.

The effort is a collaboration among organizations that lead in the development and application of the survey and analysis methods used—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. The project will lead to a substantial improvement in the reliability of the Navy's impact assessments and the Navy's ability to undertake population monitoring in training and testing areas. The Navy will benefit from having a collaborative approach in advancing 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 Colombia.

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.

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

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 REMUS 600s).

The following three ongoing projects are summarized in this section.

1. Project 12 Integrated Real-time Autonomous PAM System
2. Project 21 Extended Duration Acoustic Tagging of Right Whales
3. Project 27 High Fidelity Acoustic and Fine-scale Movement Tags


Humpback whale.

Integrated Real-time Autonomous PAM System

Principal Investigators:
Philip Abbot and Vince Premus
Project Status: Ongoing, 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 demonstrates the potential for a powered autonomous underwater vehicle (AUV), equipped with a passive acoustic sensor array, to provide reduced-cost and 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 high-resolution estimates of animal density versus bearing.

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 project demonstrates the potential for a powered autonomous underwater vehicle…to provide reduced-cost and improved acoustic monitoring and survey capabilities for Navy at-sea training and testing activities.

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

REMUS being deployed during a technology test.
Mandy Shoemaker

During 2016, the project team tested the real-time monitoring capabilities of the IRAP system at 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 2017 platform demonstration, planned to occur on the Southern California off-shore range (SCORE), had to be delayed and is now planned for early 2018. Work during the year focused on software and data handling refinements, resolving logistical needs for the SCORE demonstration and conducting an IRAP system test off the New England coast.

The sensor and processing technology comprising IRAP can be employed on multiple autonomous platforms, including the REMUS 600, the SLOCUM G2, and the LRI Waveglider SV-3. Several comparison criteria—e.g., cost, availability, propulsion and navigation methods, energy source, etc.—have been assessed during the project period.

This technology could help the Navy's Marine Species Monitoring program to determine presence and abundance of both high- and low-frequency marine mammal vocalizations, and 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.

Extended Duration Acoustic Tagging of Right Whales

Principal Investigator: Susan Parks
Project Status: Ongoing, Project 21

NEED

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

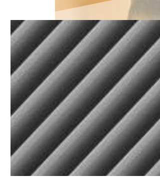
The Navy needs more information on aspects of marine mammal behavior in response to Navy training and testing activities. Two related topics within this need are: 1) research on how different variables may impact the behavioral response of the animal, including range between the source and animal during 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 and glue attachment methods for non-invasive tags to provide the longer sampling times needed to improve animal movement and behavioral response data collection. This study will be the first to apply the newly developed attachment system to a free-ranging baleen whale. The project plan is to test the attachment of DTAG-3s using micro-texture 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.

During the 2017 monitoring season, poor tagging conditions—both sea conditions and few right whales—prevented testing the new tag attachments on right whales. The team subsequently was able to conduct a few tests of suction cups with micro-texture on humpback whales in the Northeast during summer 2017. Researchers are analyzing the results of the humpback tagging to identify possible design modifications. The team plans to add the biocompatible glues with the micro-texture design for testing during the 2018 right whale monitoring season.



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

Successful use of the new attachment method and longer-term recording tags will open the potential for attaching these tags to a broad range of endangered

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.

species in multiple Navy areas of interest, significantly extending acoustic data collection timeframes. The products from this research will include micro-textured machined suction cups in the final form as determined from results of field testing. A publication summarizing results will be completed.

About the Principal Investigator

Susan Parks is an assistant 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.

A key collaborator on this project is Doug Nowacek from the Duke University Marine Lab.

Attaching a monitoring tag to a whale.
Matthew Bowers, permit 14791

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.

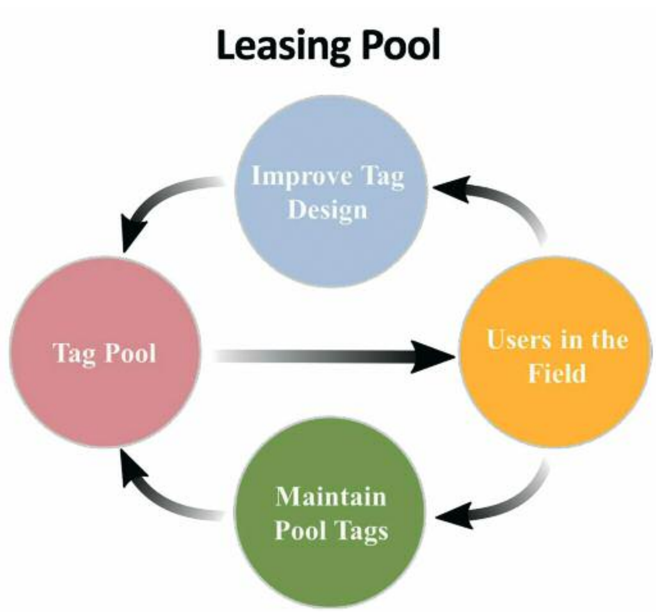
PROJECT

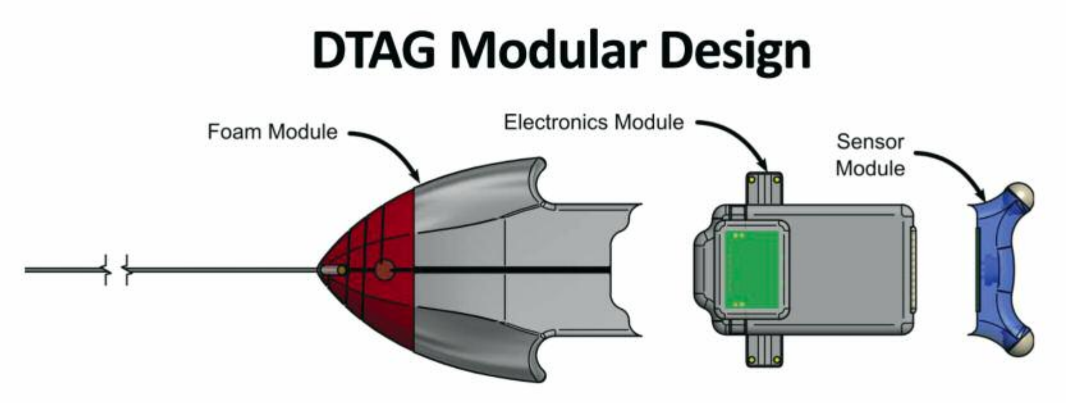
One type of acoustic tag often used in research and monitoring is the digital acoustic recording tag (DTAG). DTAGs are highly integrated, compact, low-power, high fidelity acoustic bio-logging tags that are well suited for studying both deep diving beaked whales and large baleen whales. The combination 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 MMB program, include lower cost, production efficiency, reduced size for small odontocetes, longer duration attachments and wider bandwidth recordings.

An important aspect of this project is the tag leasing program, which is helping to make tags readily available and sustain tag improvements. The pool of tags is maintained at the University of Michigan. Users lease tags for their field work then return the tags to pool, where they are repaired (if needed), 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

> The DTAG-3 is a great example of a technology that is moving through the Navy's three marine resource programs.





improvements. Following any appropriate maintenance or improvements, tags are returned to the lease pool and available for users. The project expects to have 30 DTAG-3s available to the pool by 2019.

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 then implementation will occur 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 research scientist 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.

MCS2 Ryan Utah Kledzik

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 information exchange, which is necessary to harness the capabilities of aggregated data to ensure the Navy maintains information dominance.

Data that have been collected, managed or analyzed using varied techniques and methodologies can make it difficult to incorporate and use the information in the environmental compliance process. For example, data pertaining to a particular species are often quantity-limited, making it necessary to aggregate data for multiple species that are often collected from a variety of sources. However, in order to aggregate data, the data need to be comparable, raising the need for agreement on standards and metrics.

Establishing interagency and scientific community standards and metrics for how data are collected, managed and analyzed promotes data comparability and enables data aggregation from different data sets. Ensuring consistent, agreed-upon standards and metrics provides multiple benefits, including cost-effective improvements to data and results that can be utilized to establish policy and technical guidance.

Projects in this area can include standards for data collection methods, standardized data management tools, as well as establishing metrics for reporting performance of data analysis methods.

Five ongoing projects are summarized in this section.

1. Project 6 Database and Metrics for Testing Automated Signal Processing for Passive Acoustic Monitoring
2. Project 13 Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database
3. Project 15 Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments
4. Project 18 Acoustic Metadata Management for Navy Fleet Operations
5. Project 28 Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems

MCS1 Ace Rheaume

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.

> The team is constructing marine mammal sound data sets specific to particular Navy training areas in the Pacific and Atlantic oceans.

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 data set will be used during the 2018 Detection, Classification, Localization, and Density Estimation Workshop to test a variety of detectors and classifiers.

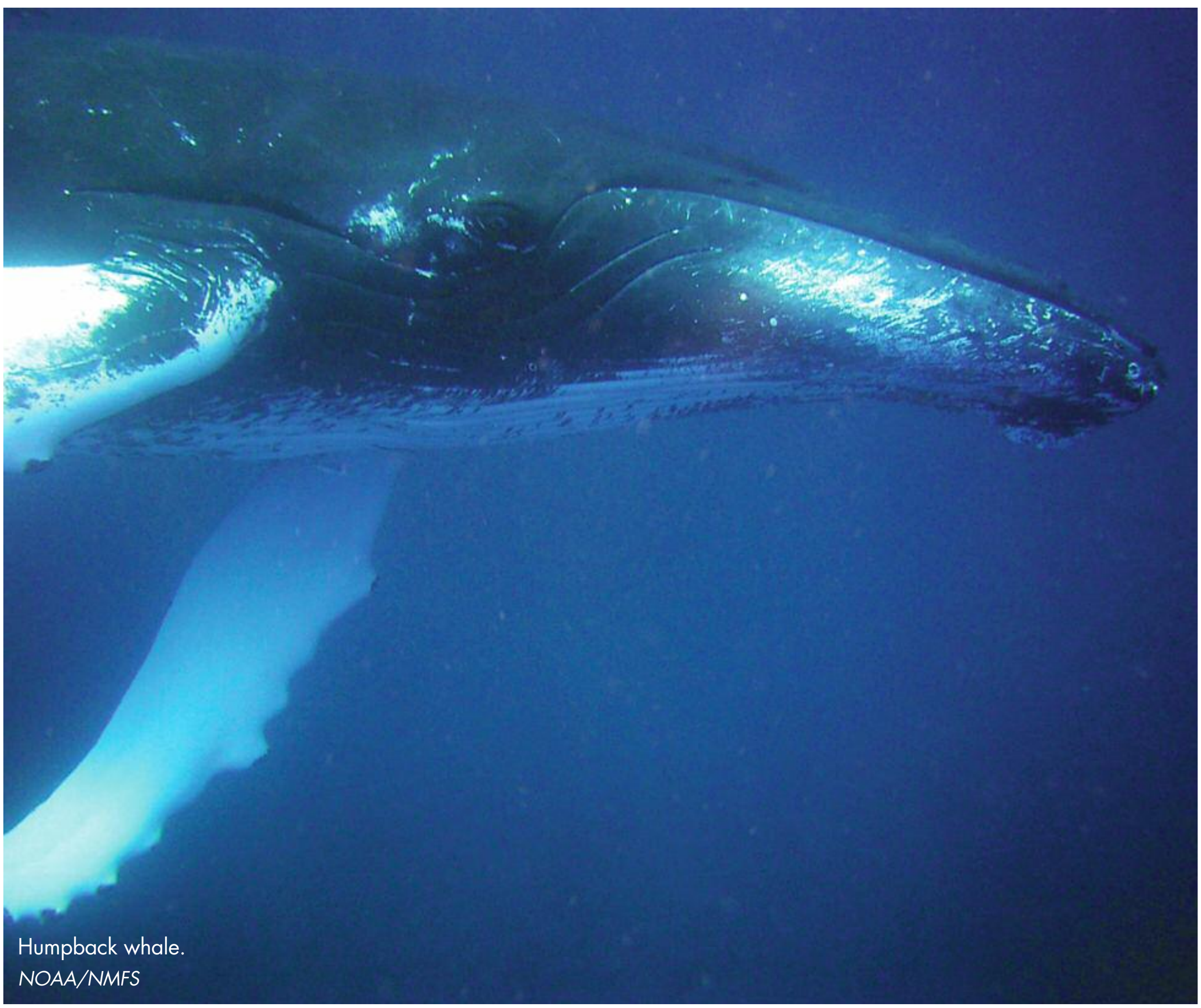
A concurrent effort has engaged members of the marine mammal detection and classification community to develop a standardized set of metrics for evaluating the performance of automatic detector and classification outputs. A metrics committee was formed in 2015 and its products are being designed to be 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.

The metrics report was nearing completion in 2017 as case studies were being finalized, and the final report is expected to be completed in 2018.

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.



Humpback whale.
NOAA/NMFS

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

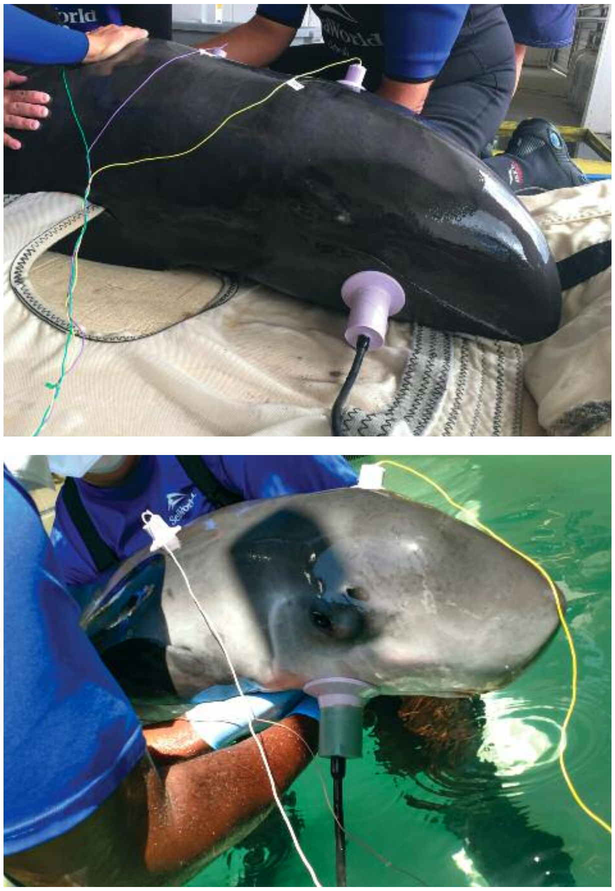
This multifaceted project is working to standardize one type of hearing threshold measurement method used in odontocetes and to increase species representation and sample sizes in hearing threshold estimates. Such standardized methods will help to ensure comparable hearing data for use in analyses conducted by the Navy as part of the environmental compliance process.

One method used to evaluate baseline hearing in marine mammals involves measuring AEPs, which are voltages produced by the brain in response to an acoustic stimulus. 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. However, different AEP methodologies can result in large differences in threshold estimates for the same species, or even the same individual. 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.

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

Efforts within the project include

- Developing and promoting a standardized AEP methodology for approval by the American National Standards Institute (ANSI)
- Updating the Evoked Response Study Tool (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.



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

A parallel project, sponsored by NOAA, is to develop a national database for archiving AEP audiograms and metadata. The database will benefit Navy compliance reporting efforts and permit applications by providing ready access to all available AEP data.

The standards working group, established in 2015, has continued its progress on drafting a proposed standard. During 2017, the group completed and revised three drafts of the standard, working with the Acoustical Society of America (ASA) Committee on Standards S3/SC1 Animal Bioacoustics. The group submitted the last draft to the ASA Standards Secretariat for administrative and format review. A final version will be submitted to the ANSI Board of Standards Review to consider for adopting as a standard.

All EVREST systems continue to receive maintenance and updates at the standing network training sessions. Technical improvements have included making it possible to determine optimal amplitude modulation/stimulus presentation rates and incorporating a new biopotential amplifier (currently being tested). Modifications in support of anticipated standards requirements are being prepared and steps to improve data flow for database storage are being incorporated. Once the AEP standard is completed, the EVERST systems will be fully reprogrammed to meet the standard.

Currently available EVREST systems have been put to regular use over the course of the standardization effort in order to increase species representation and sample sizes in hearing threshold estimates. Twenty-five small cetaceans representing nine species have had AEP hearing tests conducted on them by the principal investigator and stranding networks since the beginning of the project.

Stranding network trainings have been held annually and participants included both experienced network members who were refreshing their training and first-time trainees. Their training covered ways to improve test efficiency, troubleshooting, and data analysis and interpretation. Providing this training is improving the quality and the consistency of AEP data collection across the country.

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.

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

Principal Investigators: Ted Cranford, Petr Krysl
Project Status: Ongoing, 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.

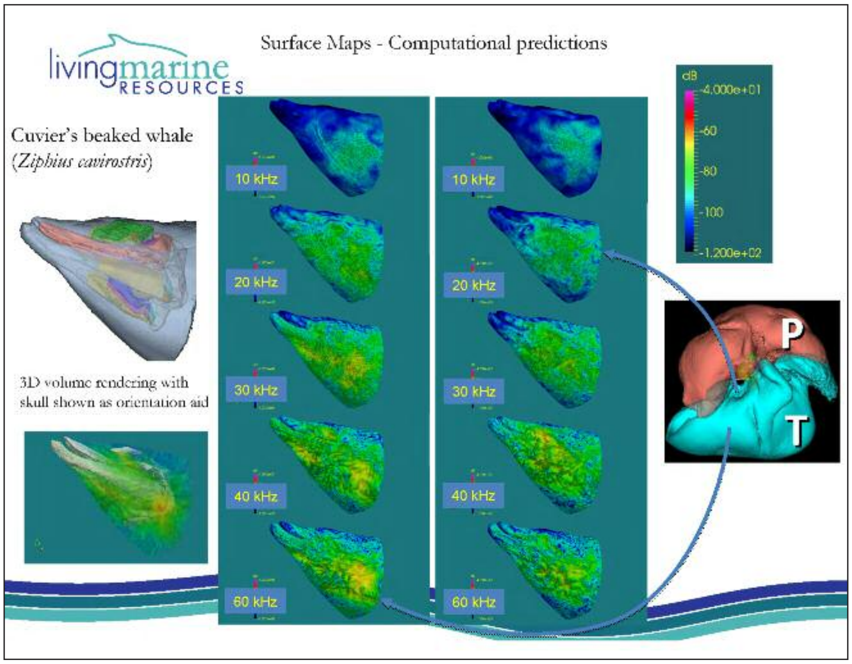
PROJECT

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 uses 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.

> Insights can be obtained from these models to help inform jawphone placement, which will be particularly useful when measuring the hearing capabilities for species not yet studied.

The project is using finite element modeling techniques, where 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 will enable the development of 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.

The project has generated surface sensitivity maps for three species, the common dolphin (*Delphinus capensis*), the bottlenose dolphin (*Tursiops truncatus*), and the 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 the maps both display similarities and vary in their details between the species across the frequencies tested. The simulations performed for the bottlenose dolphin confirmed previous work that showed the significance that details of anatomic geometry can have for acoustic function. In addition, surface maps for phase shift and time delay show consequences for sound reception mechanisms and optimal placement of jawphones.

Researchers also evaluated potential differences in the conditions under which jawphones are used for AEP testing. The two primary conditions are in-air or in-water. Surface maps are different for in-air and in-water, which may have implications for jawphone use.

During 2017 the project focused on conducting a validation experiment with a live dolphin, and analysis of results is underway at University of Hawaii. This experiment is measuring the sound pressure levels received and the time delays at a given receiver location and how that varies based on changing the location of the sound source.

These results will offer validation of the computational determination of the sound reception mechanisms associated with AEP testing using jawphones. Insights can be obtained from these models to help inform jawphone placement, which will be particularly useful when measuring the hearing capabilities for species not yet studied.

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.

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

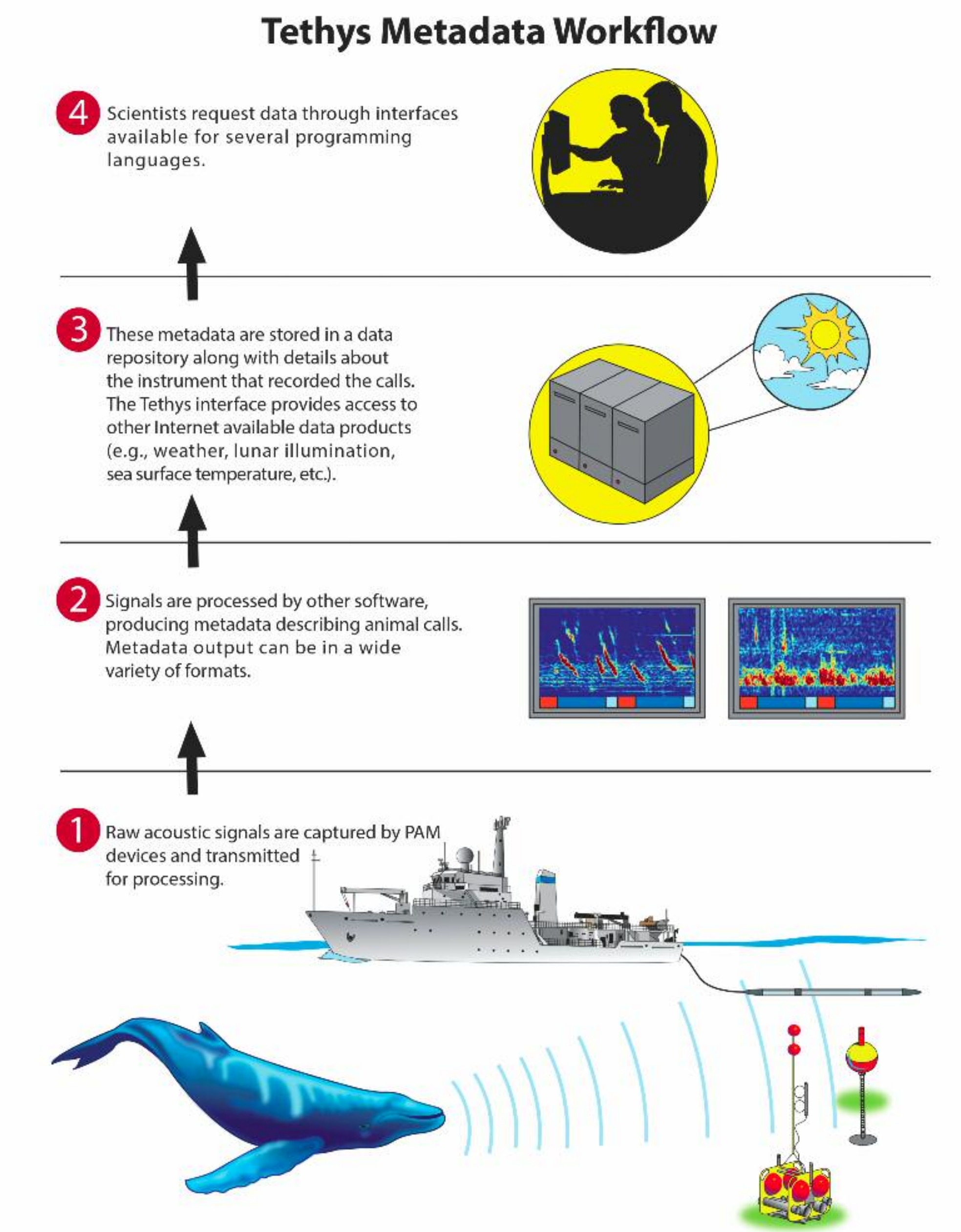
This project is conducting work to standardize long-term acoustic marine species monitoring records and to develop a reference database for Navy data management and reporting requirements. The project is using Tethys, a passive acoustic monitoring (PAM) metadata database sponsored by National Oceanographic 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.

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

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.

Progress during 2017, of particular interest for the Navy, included working closely with Navy partners, including Tyler Helble's group at the Space and Naval Warfare Systems Command, installing Tethys for the group and successfully incorporating their localization data. Other improvements included adding an open-source map server and progress on a web-based graphical user interface, which improves the query and report generation process. This will enable more efficient Navy monitoring reporting. A new Tethys software version, 2.4, being completed in 2017 will provide user benefits such as increased speed, improved handling of large documents and additional types of weekly visualizations.



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). Work during 2017 was performed with BOEM funding. 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

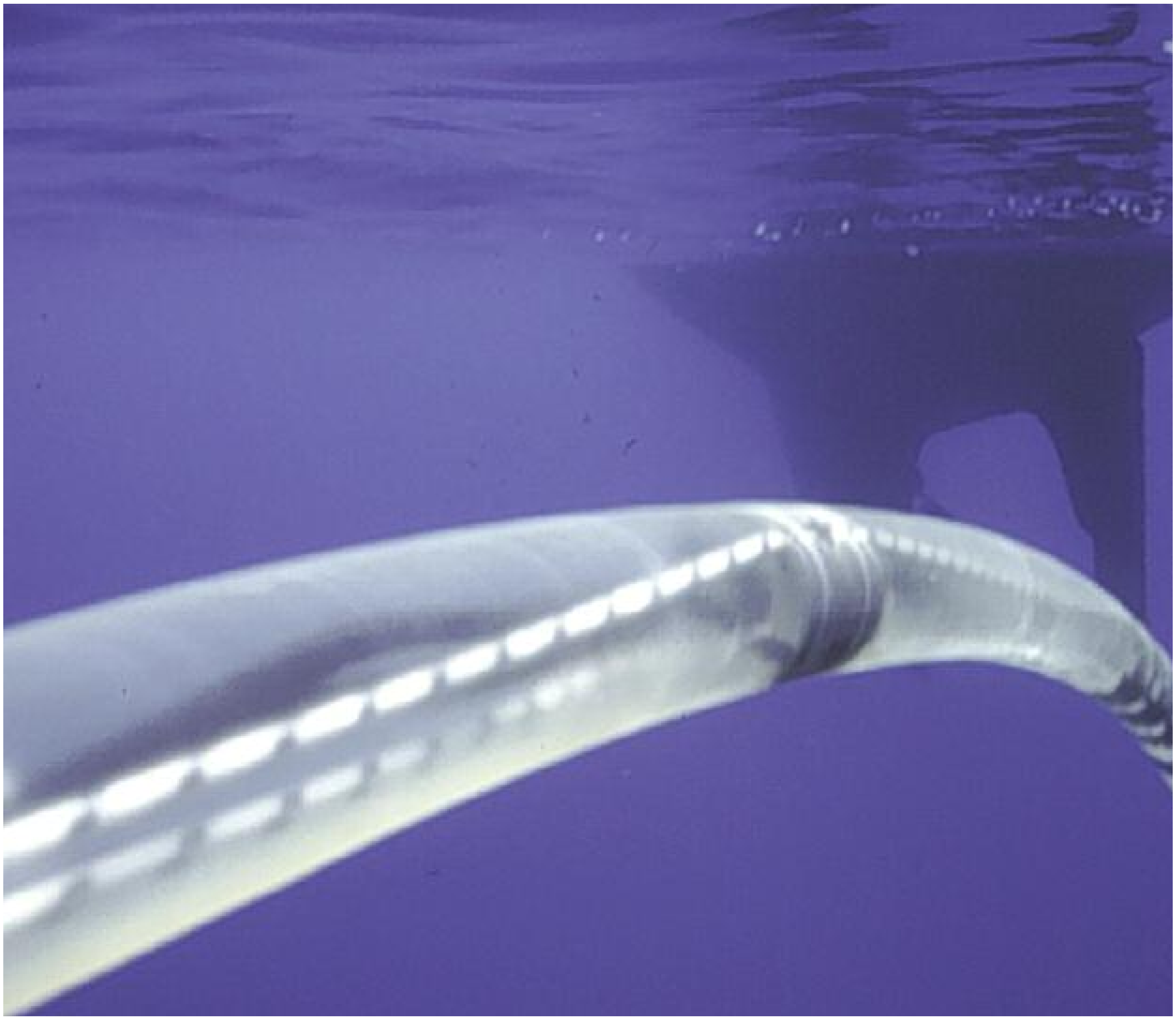
Navy monitoring utilizes a variety of PAM methods including fixed range hydrophones, fixed single sensor hydrophones, hydrophones deployed on mobile unmanned underwater vehicles (such as sea gliders, wave gliders, etc.), tags and towed cabled hydrophone arrays. Several U.S. federal agencies and departments, 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

During November 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.

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



One example of a dipole towed array deployed.
D.M. Rossi, University of Pavia

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.

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 is one ongoing project summarized in this section.

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

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.

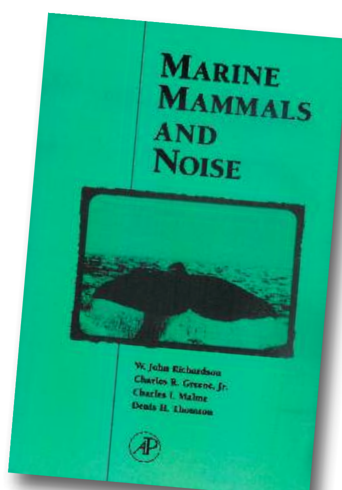
PROJECT

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.

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.

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



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.

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

As of late 2017, the team had completed Tasks 1 and 2. In addition, all analysis of available information on marine mammal hearing was completed. The project is scheduled to be completed by the end of 2018.

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.

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. Five partnerships were underway during 2017. LMR contributions to two of the five concluded during the year.

Completed Projects

Survey Software Toolkit for Data Collection, Data Workflow and Data Delivery

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 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.

This project, funded by OPNAV N45, focused on making all aspects of the data collection workflow more efficient. Coordinated guidance from both the Navy's Marine Species Monitoring program and the LMR program helped to ensure that the product met the Navy's needs. The resulting mobile data collection app, called COMPASS (Cetacean Observation and Marine Protected Animal Survey Software), structures monitoring data collection to support consistent data formats and outputs. These features are expected to help to reduce the level of effort needed both to prepare data for analyses and to generate reports.

The app, currently configured for Apple iPad® operating systems 9 and newer, displays spatial data over selected base maps. Among its many features the app includes data collection layers to help organize survey observation input, environment details (e.g., weather, sea state, visibility, etc.), a position logging option that can record iPad position at set intervals, and a GPS feature that allows the user to identify current location on the map. Users then synchronize data on the device to a host server for archiving, making the data available for viewing on other devices.

This product is a significant step forward in efficiently collecting marine species monitoring data from a variety of platforms.

The ability to review survey data from any internet-connected computer, including visualizing spatial components on high-performance web maps, supports collaboration among members of the Navy marine species monitoring community regardless of geographic location. It will offer marine species monitoring data that have undergone thorough quality control, are standardized and that provide critical information to support Navy planning.

App software was tested and evaluated by contractor and Navy personnel during 2017. It also was demonstrated to National Marine Fisheries Service staff during a recent at-sea survey. The Navy's Marine Species Monitoring program anticipates employing the app for selected monitoring efforts in 2019. This product is a significant step forward in being able to more efficiently collect marine species monitoring data from a variety of platforms.

Principal Investigator

Michael Richlen
HDR Environmental Inc.

Examining Factors That Could Influence the Acoustic Identification of Odontocete Species on Bottom-moored Recorders

To reduce the demands on acoustics analysts, there is increasing attention to using statistical algorithms (classifiers) to identify odontocete species based on the properties of the animals' whistles and clicks. Despite substantial improvements of these automatic classifiers in recent years, there could be a mismatch between how the classifiers were developed and how they may be used. Most of the species classifiers have been developed using passive acoustic data collected at the sea surface, yet Navy marine mammal monitoring often relies on moored acoustic recorders stationed at depth.

Several factors—how sound propagates through water, physical water column characteristics, bathymetry, distance between animals and receivers, the direction an animal is facing relative to the recorder, among others—could affect the sound characteristics of the signals being captured. Thus it is not known if the classifiers developed using surface data are suitable for analyzing data from recorders at depth.

This project, a partnership of ONR, LMR and U.S. Fleet Forces Command, examined how species-specific signals received at recorders at different depths are affected by these factors. The project team used both surface-deployed recorders (microMARS recorders) stationed at varying depths and bottom-moored vertical arrays of second generation Ecological Acoustic Recorders (EAR2) to obtain recordings at different depths in the water column from a variety of free-ranging odontocete species. As an experimental control condition, a single Navy-trained captive dolphin was stationed at a known depth, distance and orientation.

Field work included three data collection efforts. The first was a pilot study off the Hawaiian island of Lanai, followed by efforts off Kona, Hawaii and San Diego, California. Overall, the effect of recording depth on whistle variables and classification results varied by geographic location and encounter. Classification results varied with depth for fewer than half of the EAR2 encounters and for fewer than a quarter of microMARS encounters. Results of the control dolphin signal classifications varied more than those of the wild animal groups.

> Overall, the effect of recording depth on whistle variables and classification results varied by geographic location and encounter.

The complications that arise from the interplay between the location and orientation of whistling dolphins, the sound propagation characteristics of the water column and likely other factors such as group size and behavior require additional data collection and analysis for a more complete understanding of using classifiers under different recording scenarios.

The final report on the recently concluded effort can be found at: https://www.navymarinespeciesmonitoring.us/files/5414/9935/9699/Oswald_et_al._2017_-_Surface_vs_Depth_-_FINAL.pdf

Principal Investigators

Julie Oswald
Bio-Waves Inc. and
University of St Andrews in Scotland

Marc Lammers
Oceanwide Science Institute

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 skin samples are used to provide genetic information, particularly important for a species estimated to have only 30 to 50 remaining individuals.

Beginning in Fiscal Year 2016, LMR implemented a more formalized process for researchers to request sonobuoys. Researchers complete a Sonobuoy Request Form, LMR reviews and prioritizes the requests, and then makes the final decision on which projects receive sonobuoys. A final list is then submitted to the Sonobuoy Logistics Group to handle distribution.

All 480 available sonobuoys were allocated. Projects and organizations receiving sonobuoys during 2017 are identified in the following table.

Navy sonobuoys distributed through this process helped researcher Jessica Crance from the Alaska Fisheries Science Center's Marine Mammal Laboratory locate rarely seen North Pacific right whales in the Bering Sea. During the 2017 field effort, Crance and the other researchers tracked the signal picked up by the sonobuoys to the whales, where they were able to photograph them and take small skin samples from two whales. The skin samples are used to provide genetic information, particularly important for a species estimated to have only 30 to 50 remaining individuals.

PROJECT	ORGANIZATION
California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys	University of California at San Diego/ Scripps Institution of Oceanography
International Whaling Commission (IWC) Pacific Ocean Whale and Ecosystem Research (POWER) cruise/North Pacific Research Board (NPRB) Arctic Integrated Ecosystem Research Program (IERP) cruise/ NOAA Pacific Marine Environmental Laboratory (PMEL) cruise	National Marine Mammal Laboratory/ Alaska Fisheries Science Center
Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS) cruise	Southeast Fisheries Science Center
Mysticetes aerial surveys in the Northeast/Atlantic Marine Assessment Program for Protected Species (AMAPPS) cruise	Northeast Fisheries Science Center
Main Hawaiian Islands Survey	Pacific Islands Fisheries Science Center

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.

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.

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

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, and the analysis of audio is ongoing in 2017.

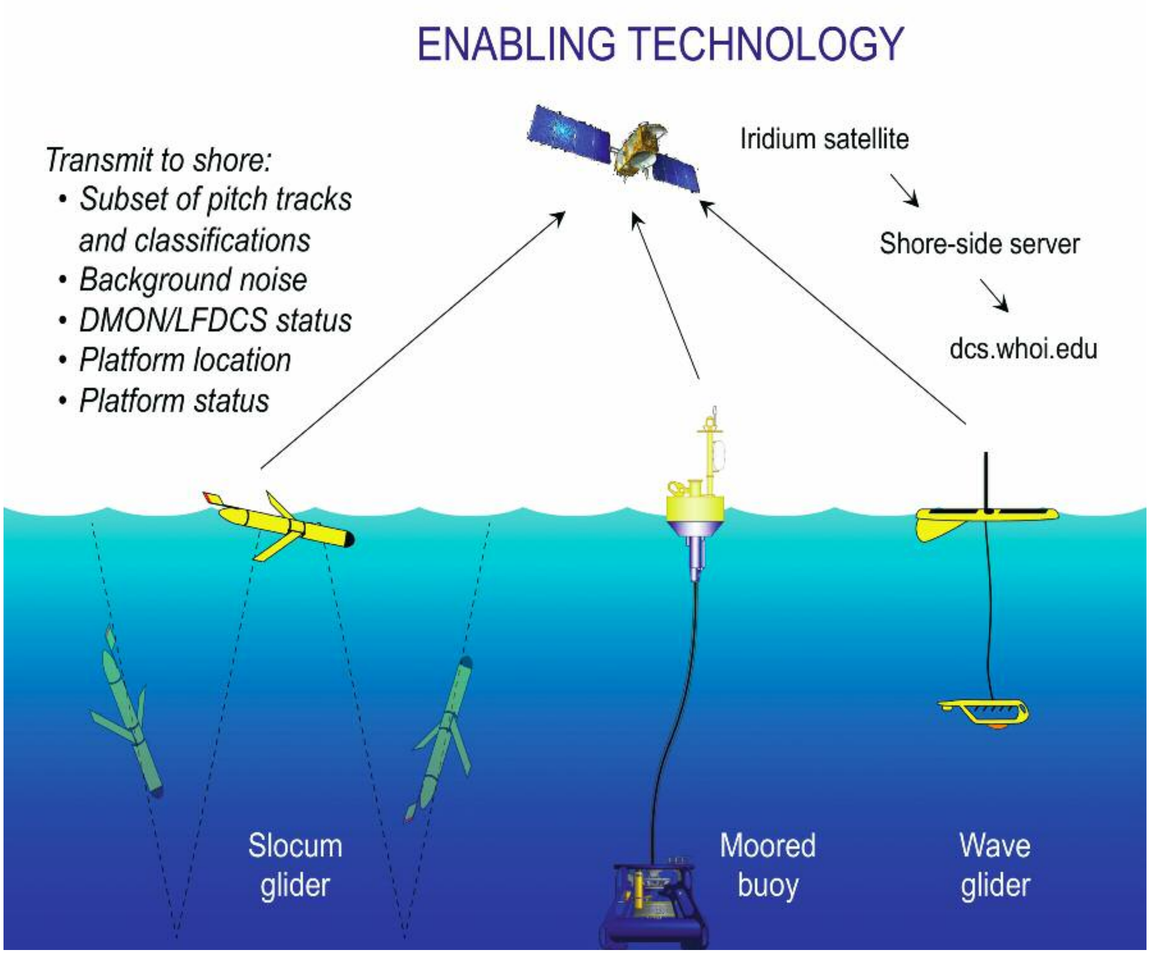
All platforms report detections to a publicly available website (dcs.whoi.edu), where platform tracks, detection information and pitch tracks are examined and analyzed by scientists. This technology package offers a useful tool to the Navy's Marine Species Monitoring program that can augment visual survey 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.



PARTNERSHIPS

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.

> 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 effort is a partnership among ONR, LMR, and Commander, Pacific Fleet. It 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 during 2017 is summarized below.

- **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 is being designed for available Navy standard models in order to automate the SPL/SEL estimation process. The basic framework of this software has been completed, and SPL and SEL levels have been automatically assigned to 17 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.

- **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 software that automatically measures whale kinematics. These data products have been applied to 17 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.

- **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 is integrating available classifiers, with modifications as needed to work on the PMRF and the Southern California Offshore ranges. The software is currently in development, with preliminary results to be presented at the 2018 Detection, Classification, Localization, and Density Estimation Workshop in June.

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.

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LOOKING AHEAD

Humpback whale.

LOOKING AHEAD.

In 2018 we look forward to seeing several 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 2018 and will be available for transition or further investigation

For example, four monitoring technology demonstration projects (two pertaining to tags and two pertaining to monitoring platforms) are scheduled to be completed in 2018 and the technologies will become available to the Navy's Marine Species Monitoring program.

LMR intends to fund one project from our Fiscal Year 2018 (FY18) Broad Agency Announcement, which was focused on a need to collect in-situ acoustic data during large explosive events to better characterize the far-field sound propagation. The results will be used to update the Navy's Acoustic Effects Model (NAEMO) in order to provide more accurate acoustic propagation modeling of explosive sources, which will be utilized to refine take estimates for environmental permits and develop more effective mitigation measures. This study will be initiated in FY18 to ensure that results will be available in time to be incorporated into the Navy's next environmental compliance cycle.

To address another need, we invited internal Navy principal investigators to submit a proposal focused on testing and comparing the performance of existing sonar detectors that locate sonar signals in passive acoustic datasets. The goal of this project is to standardize the analysis of sonar detections in passive acoustic monitoring data. Detecting sonar signals within the monitoring data helps us assess how marine mammals respond to active sonar sources. This work will enable more accurate and consistent data analysis.

Looking beyond 2018, 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 difficult and expensive place to study and many of the tools and technologies are not readily available to assist the Navy's Marine Species Monitoring program in meeting requirements in a cost effective manner. 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 impacts 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—such as ESTCP, BOEM, NMFS 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.

Ultimately, this work 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.

LMR Publications

Included here is a list of publications that became available in 2017 and that were partially or fully funded by the LMR program or that acknowledged use of data from LMR projects. 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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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
ATA.......................................Advanced Technology Attachment
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
CT ....Computerized tomography
dB re 1 μPa.....................Decibel referenced to one microPascal
DCLT ....Detection, classification, localization and tracking
DET..Detection error trade-off
DICASS ....Directional command activated sonobuoy system
DIFAR ....Directonal low-frequency analysis and recording
DMON.............................Digital acoustic monitoring instrument
DSP....................................Digital signal processor/processing
DTAG ....Digital acoustic recording tag
EIS ....Environmental Impact Statement
EOD ....Explosive Ordnance Disposal
ESA ....Endangered Species Act
EVREST..Evoked Response Study Tool
GPL...Generalized Power Law
GPS ....Global positioning system
HARP ....High-frequency Acoustic Recording Packages
HF ....High frequency
ICMP ....Integrated Comprehensive Monitoring Plan
IPR ....In-progress Review
IRAP......................................Integrated Real-Time Autonomous Passive Acoustic Monitoring
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
MMB ....Marine Mammals and Biology program (Office of Naval Research)
MMPA ....Marine Mammal Protection Act
NAVFAC EXWC........................Naval Facilities Engineering and Expeditionary Warfare Center
NAVO ....Naval Oceanographic Office
NMMF ....National Marine Mammal Foundation
NOAA ....National Oceanic and Atmospheric Administration
OE ....Opportunistic exposure
ONR ....Office of Naval Research
OPNAV N45..................Chief of Naval Operations Energy and Environmental Readiness Division
PAM ....Passive acoustic monitoring
PAS ....Pulsed active sonar
QUTR ....Quinault Training Range
RHIB...Rigid hulled inflatable boat
RDT&E ....Research, development, test and evaluation
ROC ....Receiver-operator curves
ROCCA ....Real-time Odontocete Call Classification Algorithm
SATA............................Serial Advanced Technology Attachment
SCORE ....Southern California Offshore Range
SME ....Subject matter expert
SMRT.............Sound and Motion Recording and Transmitting tag
SOAR............Southern California Anti-Submarine Warfare Range
SOCAL ....Southern California
SEL ....Sound exposure levels
SPL ....Sound pressure levels
SSC Pacific.......Space and Naval Warfare Systems Center Pacific
SYSCOM ....Systems Command
TB ....Terabytes
TRC ....Technical Review Committee
TTS..Temporary threshold shift


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