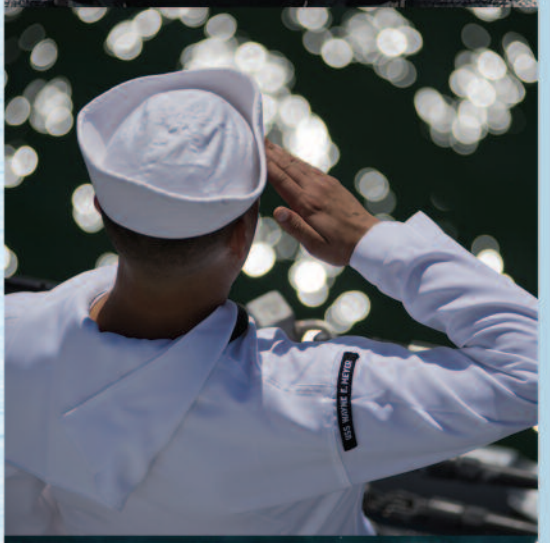
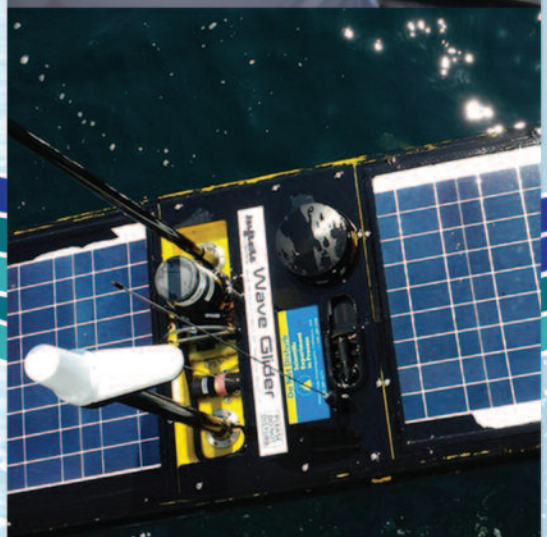




LMR

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

2016

SCIENCE • STEWARDSHIP • NAVY READINESS

livingmarine RESOURCES

TABLE OF CONTENTS

Cover images, TOP TO BOTTOM: Gray Whale, Dr. Steven Swartz; An MH-60R Sea Hawk helicopter hovers with its sonar dipping buoy lowered in front of the aircraft carrier USS John C. Stennis (CVN 74), MCS3 Josue L. Escobosa; Saluting sailor, MCS2 Benjamin Crossley; Liquid Robotics Wave Glider.
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

Gray whale.

A WORD FROM THE PROGRAM MANAGER

Welcome to the 2016 program report from the Living Marine Resources (LMR), in which we summarize the program's successes for the year and present how the research sponsored by the LMR program supports the Navy's at-sea environmental compliance process. This annual report process is a good opportunity to step back from the daily operation of the program tasks and to reflect on program goals, where the program has been, and where it is going.

To maintain operational readiness, the Navy needs to conduct ongoing training and testing. At-sea training and testing can involve the use of active sonar and explosives, which have the potential to affect marine life, and the Navy must comply with multiple Federal environmental requirements. Applicable laws from which these requirements arise include the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA) and the National Environmental Policy Act (NEPA). The LMR program plays a key role in supporting the larger Navy to understand the effects that training and testing activities may have on marine species and how we can best maintain readiness while minimizing our impact to the environment.

To secure permits for training and testing activities, the Navy's Fleet and Systems Command (SYSCOM) environmental planners, regulators, scientists and other stakeholders need credible scientific data, proven technology and methods for obtaining the data, and appropriate criteria and standards to assess the potential effects. The LMR program mission is to apply the best available science to address priority research needs and to help investigate and validate the data used in our assessment of potential effects to marine species. LMR-funded research employs rigorous and defensible science from the top experts in the field to ensure Navy readiness and promote environmental stewardship.

A priority research effort for the Navy this past year was collecting data to support the risk threshold criteria used by the Navy in acoustic effects analysis of the potential impacts to marine species. Many of the LMR program research efforts that are focused on this topic collect important hearing and behavioral response data to inform the ongoing environmental compliance process. In order to collect these data, LMR works to advance and apply knowledge in several areas including marine mammal tag technology, behavioral response research methods, acoustic recording devices and processing tools, and scientific standards for collecting hearing data.


Anu Kumar, Program Manager

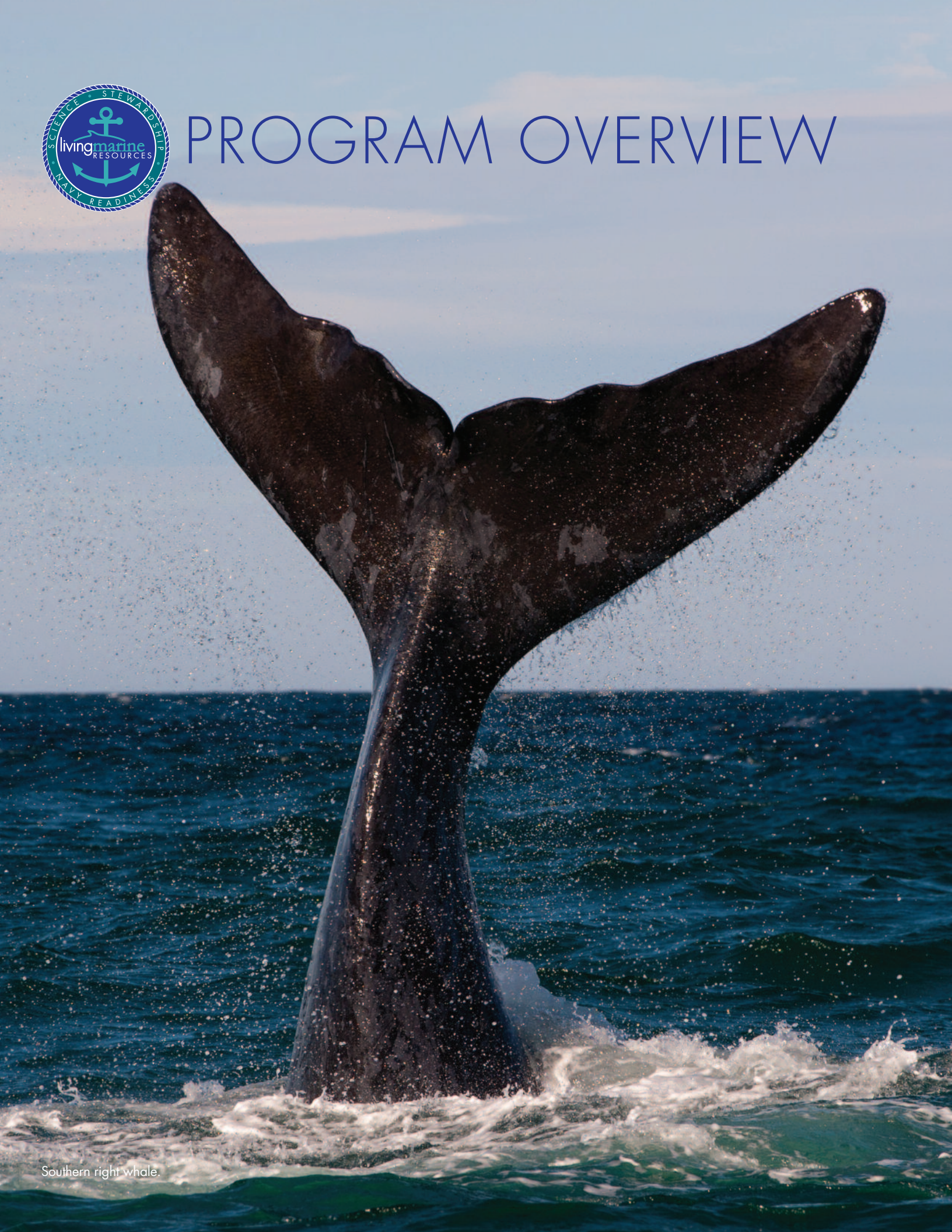
By the close of 2016, the LMR program is managing 27 projects, all carefully selected to meet Navy-defined needs. This total includes three projects that were completed during 2016 and are being transitioned to the Fleet. We also initiated eight new projects, many of which will support risk assessment criteria.

In addition, the LMR program is closely coordinating with the Office of Naval Research, the Navy Marine Species Monitoring program, and other funding organizations in partnership projects. LMR entered into two new partnership efforts in 2016. All of these efforts are summarized in this report.

I want to thank 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, for all of your efforts to sustain the LMR program throughout this past fiscal year. Your participation and support keep the program on the right track, focused on priority needs and well-coordinated with other Navy efforts. The program continues to be relevant and transparent to the Navy mission because of your critical involvement.

Anu Kumar
Program Manager

PROGRAM OVERVIEW



Southern right whale.

MISSION

In its ongoing effort to reduce potential impacts to marine mammals while meeting at-sea training and testing requirements, the U.S. Navy supports both basic and applied research to improve the understanding of marine mammals in regard to occurrence, exposure, response and consequences. The Living Marine Resources (LMR) program is responsible for applied research and works both to address the Navy's key research needs and to transition the results and technologies for use within the Navy's at-sea environmental compliance and permitting processes. The LMR program seeks to improve marine species impact analysis (including marine mammal take estimates), mitigation measures and monitoring capabilities. Key points of the LMR mission statement are:

- Improve the best available science regarding the potential impacts to marine species from Navy activities
- Improve the technology and methods available to the Navy Marine Species Monitoring program
- Preserve core Navy readiness capabilities.

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.

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.

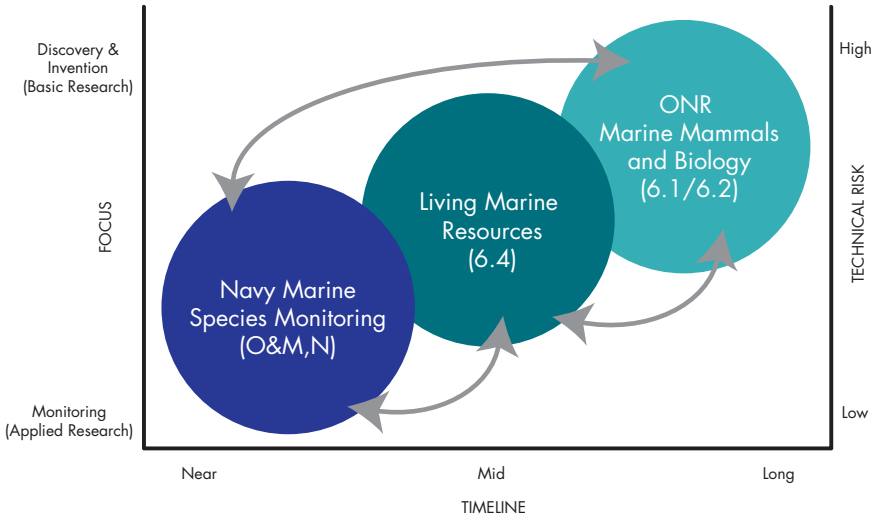
Efforts were broadened in 2000 to include a new focus on the effects of mid-frequency sonar on beaked whales—the species thought to be most sensitive to that sonar.

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 provide that type of information.

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 clear. (For more on the distinctions among organizations responsible for marine mammal efforts, see our section "Responsibility and Coordination of the Navy's Research and Monitoring Programs.") Thus in 2012, the LMR program was created as the 6.4 applied research, development, test and evaluation (RDT&E) program, and structured 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 afforded proximity to the Navy Environmental Sustainability Development to Integration (NESDI) program, on which the LMR program is modeled.

With Dr. Robert Gisiner as its first program manager, the LMR program took important first steps to establish the new program. 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 filled the deputy program manager position. The new team brought complementary skills and experience to carry the program forward. They have continued to refine the needs collection and contract process to ensure that Navy funds are efficiently expended on those projects of highest concern to Navy operation. They have emphasized a collaborative atmosphere among the principal investigators conducting projects and continually work to strengthen interagency cooperation. A high priority is keeping project efforts focused on operational Navy needs and getting results and data to end users.



RESPONSIBILITY AND COORDINATION OF THE NAVY'S RESEARCH AND MONITORING PROGRAMS

Multiple Navy organizations are involved in developing and implementing the means to meet federal permitting requirements for Navy at-sea training and testing activities. To ensure coordinated and efficient efforts, the Navy worked with regulatory agencies, marine experts and Navy personnel to develop an Integrated Comprehensive Monitoring Plan (ICMP). The Navy's ICMP provides the overarching organizing framework for the Navy's research and monitoring efforts to better understand and monitor the potential impacts on marine species. Those efforts, working from basic research to demonstration and validation to monitoring implementation, are coordinated among the following three programs:

1. The Office of Naval Research Marine Mammals and Biology program
2. The LMR program
3. The Navy Marine Species Monitoring program.

The Office of Naval Research Marine Mammals and Biology Program

The Office of Naval Research's Marine Mammals and Biology (ONR MMB) program is the Navy's basic (6.1) and early applied (6.2) research program on marine mammals and biology. As a basic research program, this program focuses on new cutting edge research topics, exploratory and developmental technological solutions such as new tag technology, and advancement of the state of the science. This program is credited with some the groundbreaking research that has improved our knowledge of marine species. Outcomes from this program can be transitioned directly to the Navy Marine Species Monitoring program if ready for integration or, for more complex research topics, projects are transitioned to the LMR program to continue to develop, demonstrate and validate solutions.

The Living Marine Resources Program

Relative to the Navy's other marine species programs, the LMR program focuses on late stage applied research (6.4) and seeks to develop, demonstrate, validate and assess data and technology solutions to study living marine resources. The LMR program is structured to be customer focused and to address the needs of the Navy's at-sea environmental compliance community. To promote ongoing coordination among the three marine species programs, the program manager from ONR MMB and representatives from the Marine Species Monitoring program are members of the LMRAC (described in a following section).

As the chart on the previous page shows, there is significant interplay of projects and support among the three programs. For example, 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. In one 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.

To move technological solutions forward to implementation, the LMR program has the capability and resources to address successful technology integration into the Navy Marine Species Monitoring program. This can be accomplished by defining technology transition agreements at the initiation of a project and setting up a transition plan that may include patent rights agreements, technological availability, end-user training and feedback during integration.

Navy Marine Species Monitoring Program

The Navy Marine Species Monitoring program is an important part of the Navy's regulatory compliance process associated with the MMPA and the ESA. The Navy is responsible for meeting specific requirements for monitoring and reporting on military training and testing activities involving active sonar and the use of explosives/explosive munitions. The Marine Species Monitoring program is a direct outcome of MMPA Letters of Authorization issued to the Fleet and SYSCOM activities.

The Marine Species Monitoring program typically uses tools that have already been developed under the ONR MMB program and field tested/validated or developed by the LMR program. For example, most of the autonomous passive acoustic monitoring devices that are currently being used were initially developed and tested under research funding from ONR. This was followed by years of field demonstrations and refinements to the devices by the LMR program. These devices are now used as a regular component of the monitoring program and represent a successful transition from basic research to the end user.

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.

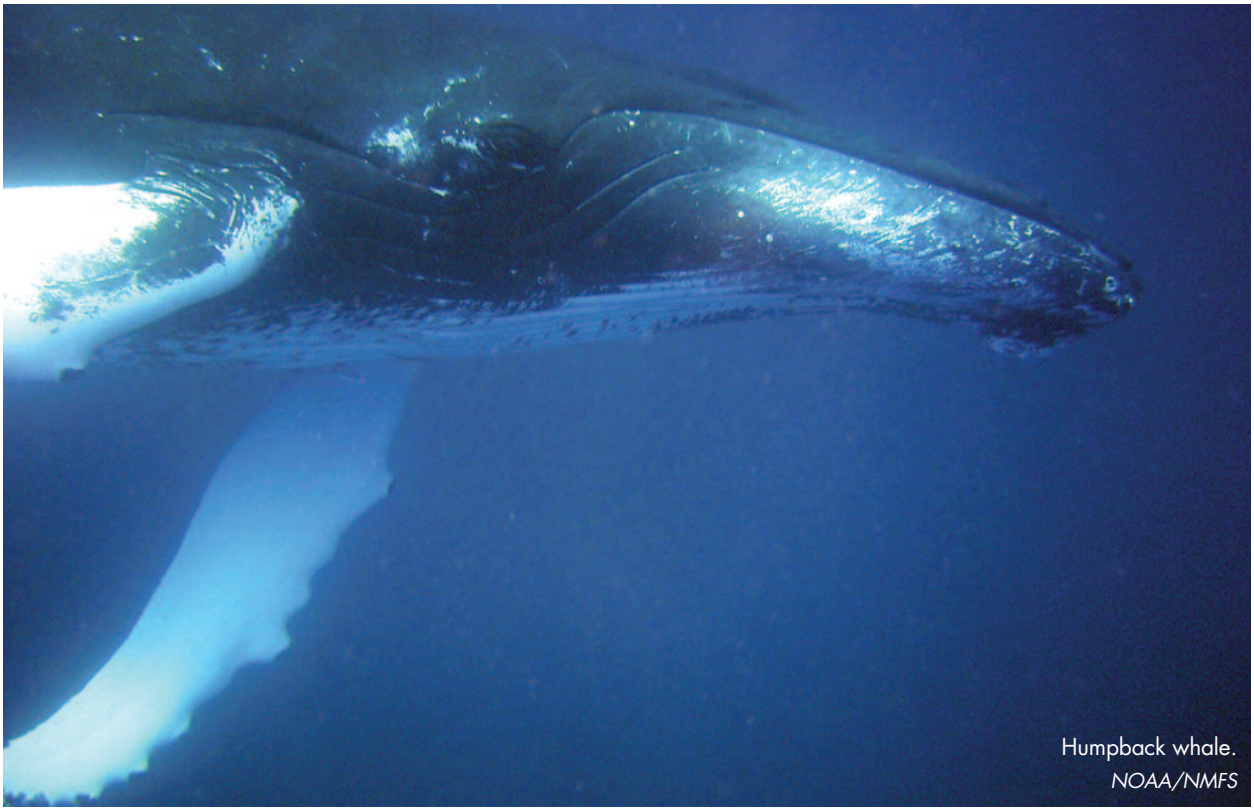
LMR Advisory Committee

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
- Commander, U.S. Pacific Fleet (PACFLT)
- U.S. Fleet Forces Command (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).

Technical Review Committee

The purpose of the TRC is to serve as an expert panel to review proposals and provide feedback to the Navy regarding their technical sufficiency. Based on the need topics the Navy solicits proposals for each year, 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



Humpback whale.
NOAA/NMFS

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 conducting 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, discussed below, are:

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

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

Program Investment Areas

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

1. **Data to support risk threshold criteria.**
   Conduct research regarding potential impacts to marine species from Navy training and testing activities, primarily focused on potential impacts from sound.

Risk threshold criteria are critical to the Navy's training range permitting process and understanding potential impacts on species present in range areas. Projects in this area can include hearing studies, sound exposure and behavioral response studies.

2. **Improved collection and processing of protected species data in areas of Navy interest.**
   Develop methods to improve the ability to process large amounts of marine species data and provide cost-effective solutions to enhance marine species monitoring capabilities.

   For passive acoustic monitoring (PAM) technology to be efficiently utilized, reliable, automated software and signal processing systems designed for users with relatively little or no subject matter expertise are needed to help detect and classify marine mammal sounds. Projects in this area can include new detection and classification algorithms and automated processing tools for passive acoustic monitoring data.

3. **Monitoring technology demonstrations.**
   Demonstrate technologies that offer to enhance marine species monitoring capabilities.

   The PAM programs being conducted on Navy ranges employ a variety of platforms, from fixed seafloor hydrophones—which limit the range of detection coverage—to hydrophone arrays that are towed, mounted on platforms, or drifting. As new sensor array and embedded processor technologies becomes available they could offer increased detection range performance, spatial resolution, and if successful, improved density estimation. Projects in this area can include new PAM technologies and platforms such as gliders.

4. **Standards and metrics.**
   Establish interagency and scientific community standards and metrics to evaluate marine species data to provide comparable results.

   Data generated by varied techniques and methodologies can pose issues for managing and analyzing the data. The sheer volume of data requires a standardized set of metrics to assess the performance of algorithms used to analyze passive acoustic data. Potential discrepancies across data sets raise the need for agreement on data standards. Projects in this area can include standards for hearing studies, as well as detector and classifier performance analysis standards.

5. **Education and outreach, emergent opportunities.**
   Support education and outreach on LMR-funded research investments and new scientific methods available to the broader scientific community. Consider emergent research topics of priority interest to the Navy.

   This investment area includes a variety of potential education and outreach efforts. As the program matures and more projects are transitioned into implementation, the number of efforts under this area could increase. Projects in the area can include subject-specific publications and other study topics needed by the Navy.

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 to limit operational constraints
- Identifies an existing gap in knowledge, technology and/or capability in order to provide flexibility to the Navy to achieve the mission
- Fullfills 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. Submitted needs are validated and ranked by the LMRAC, and then recommendations are made to the OPNAV N45 resource sponsor.

Approved needs with currently active or recently completed projects are listed below. LMR-sponsored projects are assigned within a need category. The need associated with a given project is identified in the project summaries presented in the "Program Portfolio" section of this report.

- N-0001-13: Assessing and Mitigating the Effects of Noise on Living Marine Resources
- N-0006-13: Demonstration of Remote Passive Acoustic Sensing Technology
- N-0011-13: Behavioral Responses of Marine Mammals to Navy Sound Sources

- N-0012-13: Hearing and Auditory System Information for Hearing-based Risk Criteria
- N-0020-13: Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data
- N-0077-15: Population Density Estimation from Passive Acoustic Monitoring Data
- N-0088-15: Marine Species Monitoring Data Collection Toolkit Development
- N-0096-15: Hearing Measurements in a Broad Range of Marine Mammal Species
- N-0102-16: Behavioral Response Research to Study the Effects of Sound on Marine Mammals
- N-0103-16: Marine Species Hearing Research Related to the Acoustic Effects Criteria

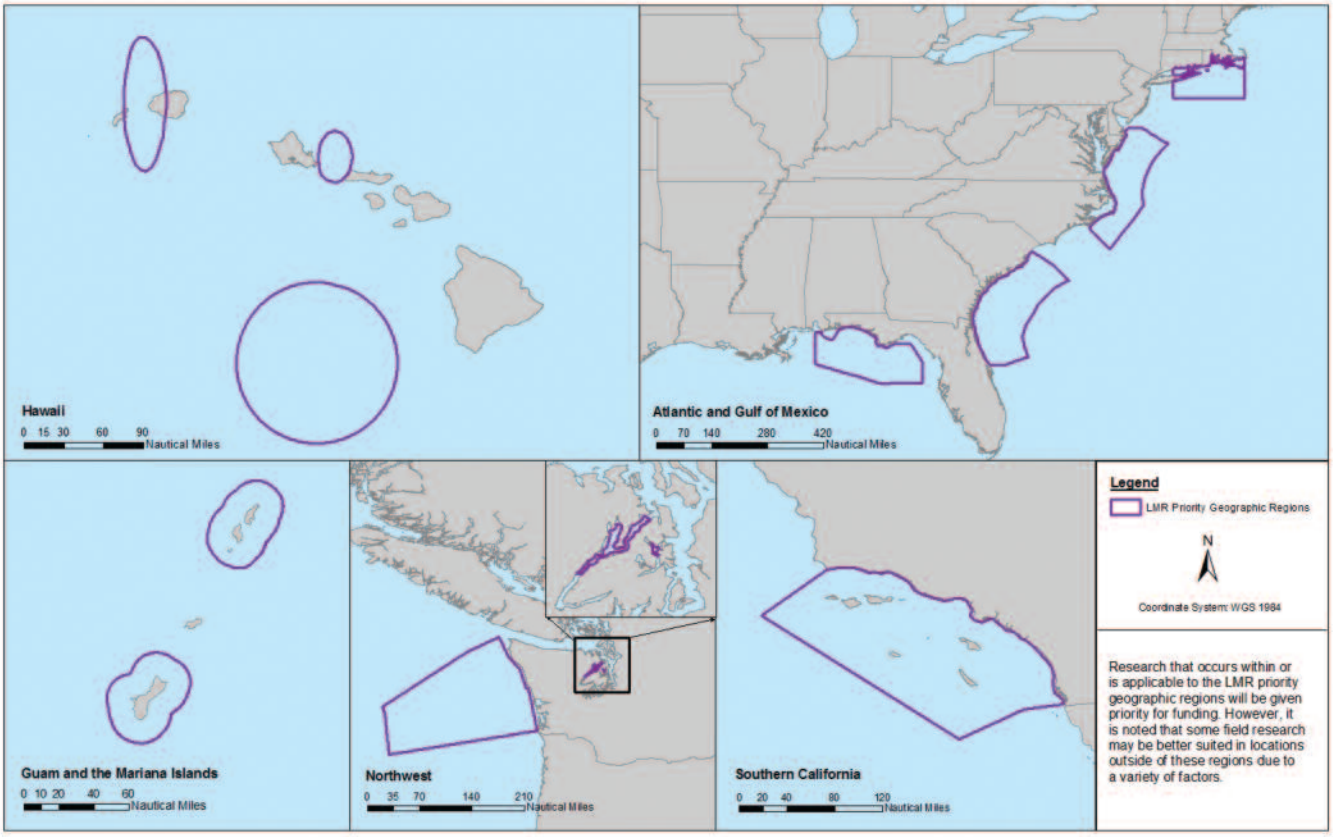
Priority Species and Geographic Regions

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. 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 requested in a 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 these regions.



LMR Priority Geographic 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—includes a review to identify those pre-proposals of greatest interest for development into a full proposal, a full proposal review and 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 Navy needs, the program works to move the demonstrated solutions out of research and into the hands of the appropriate Navy end-users. While this stage represents the final step in the formal project process, the LMR program continues 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

Fin whale.

to ensure clear communication among all participants and interested parties. The primary tools for these efforts are summarized below.

LMR Website

Note: Just prior to this report's printing, the LMR website underwent several changes. This section reflects new information for the location of the public site.

The program website has served as a centralized repository for information pertaining to program management and project execution. The management site, which requires approved login information, is a key tool for supporting the program's annual process of soliciting Navy needs, soliciting pre-proposals and full proposals and tracking project progress.

The public site includes links our newsletter, *LMR News*, fact sheets ("Project Highlights" tab) and our annual report. This information can be found at greenfleet.dodlive.mil/LMR.

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

Project Fact Sheets

Fact sheets highlighting key aspects of LMR-funded projects provide a quick view into program investments. The fact sheets 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, integration issues and project accomplishments, and
- Determine if any corrective actions are needed.

A template for preparing an IPR presentation is available from the program office.

Highlights from the 2016 IPR can be found in the fall-16 issue of *LMR News*.

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 remains on track to meet the Navy's needs.

Northern Right whale dolphins.

PROGRAM PORTFOLIO

Projects & Partnerships

Sperm whale.

The summaries of LMR projects presented in this section are in the following order: completed projects, by investment area (ongoing and new start projects) and partnership projects (ongoing and new start projects).

Completed Projects

Three projects were completed during 2016, including the first project ever funded by the LMR program, Marine Mammal Monitoring on Ranges. Results of each of the completed projects are being transitioned to Navy end users.

Marine Mammal Monitoring on Ranges

Principal Investigator: David Moretti
Project Status: Completed, Project 12-1

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

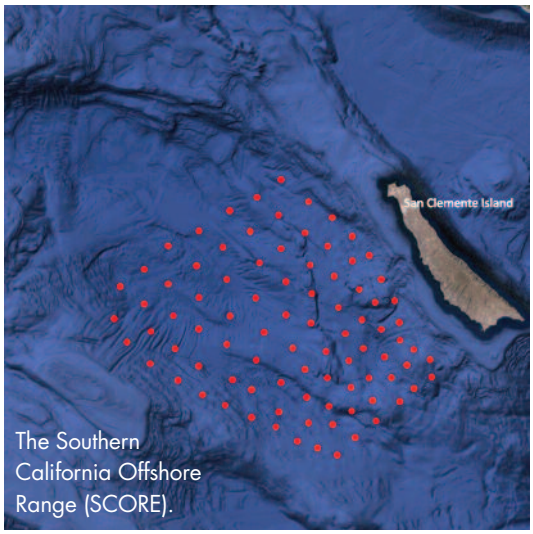
The Marine Mammal Monitoring on Navy Ranges (M3R) program has been a multi-year, collaborative effort utilizing existing hydrophone (underwater microphone) arrays on Navy ranges to expand knowledge about marine mammal presence, abundance and behavior using passive acoustic monitoring, visual observation, biological sampling and satellite tags.

The goals of the M3R program have been to:

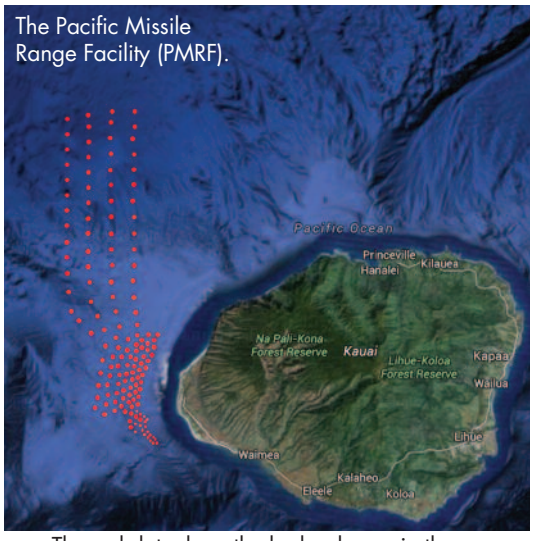
1. Develop automated passive acoustic marine mammal detection, localization, classification and display tools using existing Navy undersea hydrophone arrays and integrate visual and satellite monitoring methods to leverage the combination of these methods to study marine mammals on Navy ranges.

2. Study and measure animal responses to Navy activities, including mid-frequency active sonar (MFAS), with a focus on beaked whales.

The Atlantic Undersea Test and Evaluation Center (AUTEC).



The Southern California Offshore Range (SCORE).



The Pacific Missile Range Facility (PMRF).

The red dots show the hydrophones in the arrays.

3. Provide scientifically defensible behavioral response metrics for sensitive species, like beaked whales, which can be used to inform regulatory risk criteria and provide insight into the cumulative effect of repeated sonar exposure.

4. Provide baseline population density, abundance and habitat usage data for Navy risk analyses and permit applications covering training and testing activities on the ranges.

The Office of Naval Research (ONR) initiated M3R in 2000 to investigate the possibility of leveraging existing Navy range hydrophones to monitor marine mammals. This effort has led to significant advances in marine mammal passive acoustic monitoring. As years of marine mammal research have revealed, different species vocalize at different frequencies and have distinguishing types of sounds (clicks, series of clicks, whistles, moans, hums, etc.). It was recognized that vocalizations could be detected in nearly real-time on range hydrophones and could be used to study marine mammals *in-situ*.

The ONR project documented the presence of Blainville's beaked whales on a Navy range where MFAS was routinely used. Early steps in the project focused on developing monitoring algorithms and implementing them on the existing range Digital Signal Processor (DSP). Subsequent steps in that project included designing and implementing a stand-alone Linux cluster-base architecture. M3R inspired the range operational community to adopt the architecture for use on the major Navy ranges as the main range tracking signal processor for training and testing.

In 2009, the core M3R program was transitioned from ONR to LMR and prototype technologies were extended and used to study predominant marine mammal species, particularly beaked whales, on the Navy's instrumented ranges.

ONR investments have continued to play a vital role in analyzing M3R observations as integrated models of animal response to sound, and further study of the possible biological significance of those responses.

Throughout, the passive acoustics data have been verified using on-water sighting data (both photo and tag data) that were collected to verify the detected species and document their physical behavior, group size and population demographics. This work required multiple field efforts during which satellite tags were attached to selected animals to measure both their dive behavior and their movement over the span of months both on and off the range. When possible, these data have been evaluated along with precise ship tracks and sonar received level measurements to investigate the effects of repeated sonar exposure on cetaceans.

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

The focus of M3R has been on deep diving Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales, which have been the primary species present in stranding incidents related to sonar. While these species are extraordinarily difficult to locate and tag, the real-time passive acoustic monitoring capability of M3R proved to be a significant aid to the on-water field teams. A synergistic relationship has been cultivated in which M3R passive acoustic monitoring is used to direct on-water teams to vocalizing animals. The teams collect visual and biopsy data, and deploy tags to relay

data directly off the animal. These data are then used to inform the analyses of passive acoustic data.

M3R's fundamental structure and capabilities underlie a wide range of efforts that support Navy at-sea training. The program developed a DSP architecture that incorporates hardware and software to capture and process marine mammal sounds, classify selected species of marine mammals by their vocalizations, estimate locations and display the results in both time and frequency. Real-time detection reports are archived and available for post-analysis.

The M3R data have been instrumental in expanding the Navy's understanding of behavioral responses of whales, particularly beaked whales, to Navy at-sea training activities. More specifically, data have supported:

- Validating the Navy Acoustic Effects Model (NAEMO)
- Verifying functionality of several passive acoustic monitoring platforms (e.g., gliders, drifting buoys, towed arrays)
- Estimating long-term trends in animal abundance
- Assessing behavioral responses of marine mammals to training activities
- Developing behavioral risk functions for Blainville's and Cuvier's beaked whales, and
- Providing tools to investigate the cumulative effect of repeated MFAS exposure on beaked whales.

The improved behavioral risk criteria resulting from the extensive data collected under M3R are being integrated into the development of beaked whale behavioral risk functions that are critical to the Navy's acoustic impact analysis; a major component of the Navy's environmental compliance requirements.

The M3R program has been integrated at three Navy undersea ranges equipped with arrays of broadly spaced (1-4 miles), bottom-mounted hydrophones:

1. The Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas
2. The Southern California Offshore Range (SCORE) at San Clemente Island, California
3. The Pacific Missile Range Facility (PMRF) in Barking Sands, Hawaii.

A fourth undersea range, the undersea warfare training range (USWTR) under development off Jacksonville, Florida, had a prototype three-node system installed in 2016.

The core capabilities and operation of M3R have been transitioned to the Navy Marine Species Monitoring program. The M3R systems allow the monitoring of vocalizing animals on all range hydrophones. Archives are created that contain both detection and localizations reports. These data are then being used to estimate long-term abundance of beaked whales and to inform on-

The M3R data have been instrumental in expanding the Navy's understanding of behavioral responses of whales, particularly beaked whales, to Navy at-sea training activities.

going studies as to the effect of MFAS on selected species. During the transition, the M3R project team completed significant system updates at all three ranges (AUTEC, SCORE, PMRF), improved system stability and upgraded hardware, installed packet recorders to archive raw acoustic data and completed the user manual. User displays and documentation were developed that allow local range technicians to operate the system and collect the necessary data.

Looking ahead, the identical system architectures employed by both the M3R system and range tracking systems will support sustainment of an overall integrated system software repository. This ensures that the M3R algorithms are maintained under the structured source code control implemented for range signal processing

systems, thus helping the Navy to protect its long-term investment and reduce the maintenance costs for both systems. It also will ensure that the system remains active and meets the current Department of Defense requirements for Information Assurance. M3R will be available for further expansion and development by Navy and, through collaboration with the M3R team, can be further developed by outside scientists.

As the core function of the M3R technology continues to be implemented, the breadth of data available on marine mammals will substantially increase. This will help to provide insight on baseline cetacean behavior and the potential effects from training and testing. The system also provides near real-time marine mammal monitoring capabilities in support of specific range activities on a limited basis. The system can be operated by existing Navy range personnel to collect data prior to, during and after training exercises.

About the Principal Investigators

The M3R lead, David Moretti, is the principal investigator at 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.

Co-principal investigators include — AUTEC research team: Diane Claridge, (Bahamas Marine Mammal Research Organization) and John Durban (National Oceanographic and Atmospheric Administration); SCORE research team: Erin Falcone, (Marine Ecology and Telemetry Research), Greg Schorr (Marine Ecology and Telemetry Research); PMRF research team: Robin Baird (Cascadia Research Collective) and Daniel Webster (Cascadia Research Collective); Holger Klinck (Cornell University); Len Thomas (University of St Andrews, Scotland), Elizabeth Henderson (SPAWAR Systems Center Pacific), Phil Abbot (OASIS Inc.)

Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals

Principal Investigator: Tyler Helble
Project Status: Completed, Project 14-8

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

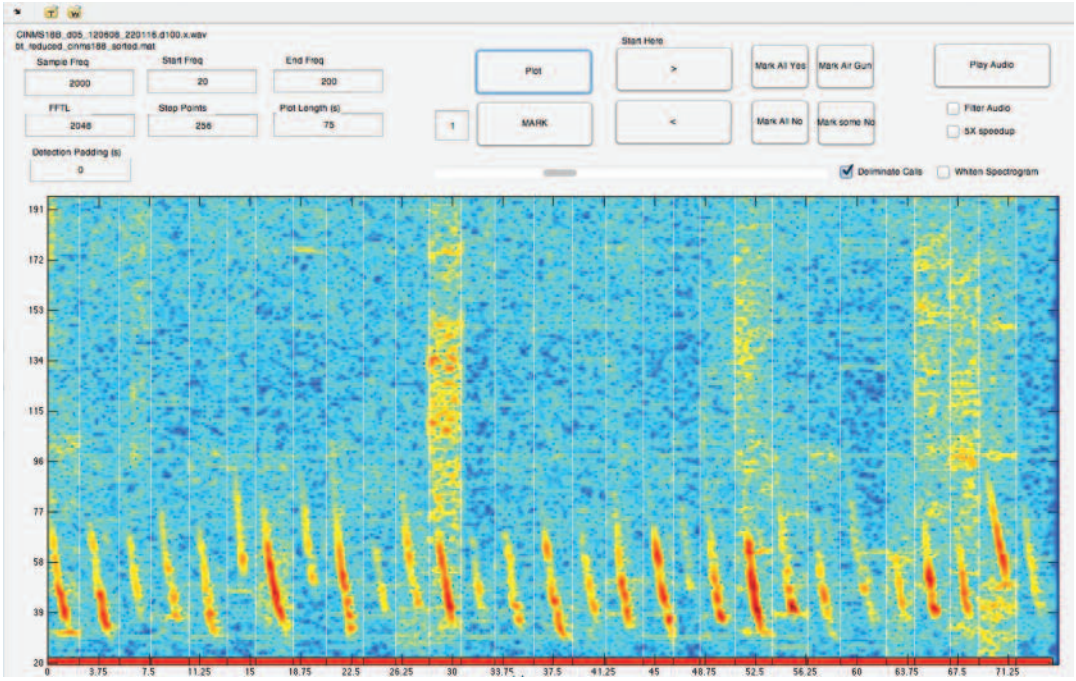
While PAM is a proven means of detecting and classifying vocally active marine mammals, the data collected by PAM systems require a significant amount of manual examination by human operators. This project has worked to automate this process to a greater degree.

The project team has applied the methods and approaches developed for detecting active and passive sonar to the Navy's monitoring of marine mammal populations.

> Automated detectors... have vastly reduced the time and cost for human operators to manually examine a data set.

The project applies the Generalized Power Law (GPL) processor, which was developed as part of a previous ONR project. This processor is considered the optimal detector for transient signals, and has been used extensively with great success in humpback whale data collection by the High-frequency Acoustic Recording Packages (HARP) that are currently being used for PAM at several Navy testing and training ranges.

Although the theoretical foundation for developing optimal and near-optimal detectors is well established, an "art" still exists when developing practical detectors for use with real data. For example, any algorithms developed for GPL processing are constrained by the need to accommodate the local noise environment as well as noise created by the platform itself. In addition, ocean bathymetry greatly influ-



Spectrograms of GPL detections shown in the graphical user interface (GUI) for blue whale "D" calls, often made during foraging activity. The GUI allows the operator to quickly accept/reject detections provided by GPL.

ences PAM readings. For these reasons, it is not feasible to create a fully automated system. Instead, this project focused on designing a system that "calls out" potential signals of interest for examination by a human operator.

Working closely with other LMR-sponsored project teams, this project effort first adjusted GPL algorithms for use with specific marine mammals and then tested these algorithms with data from existing PAM systems on Navy ranges. Detected call counts were corrected for environmental properties at the recording sites so that the resulting "environmentally calibrated" call count densities can be used to assess trends in call densities.

The project team calibrated the GPL detectors for three species of marine mammals at PMRF in Hawaii and three species from HARP recordings deployed throughout southern California. Whale track lines have also been provided for several species at both locations.

This project, which concluded in 2016, has improved the Navy's PAM capabilities in two critical ways. First, its robust, automated detectors, which are optimized for specific marine mammal species, have vastly reduced the time and cost for human operators to manually examine a data set. Second, this effort has provided methods for calibrating the detector output call counts for spatially and temporally varying ocean environmental conditions. This is a necessary step in using passive acoustic data for estimating call densities.

About the Principal Investigator

Tyler Helble is an engineer at the Space and Naval Warfare Systems Command in San Diego working on Autonomous Underwater Vehicle (AUV) systems, PAM and signal processing and whale acoustics. He holds a Ph.D. in Oceanography from the University of California, San Diego.

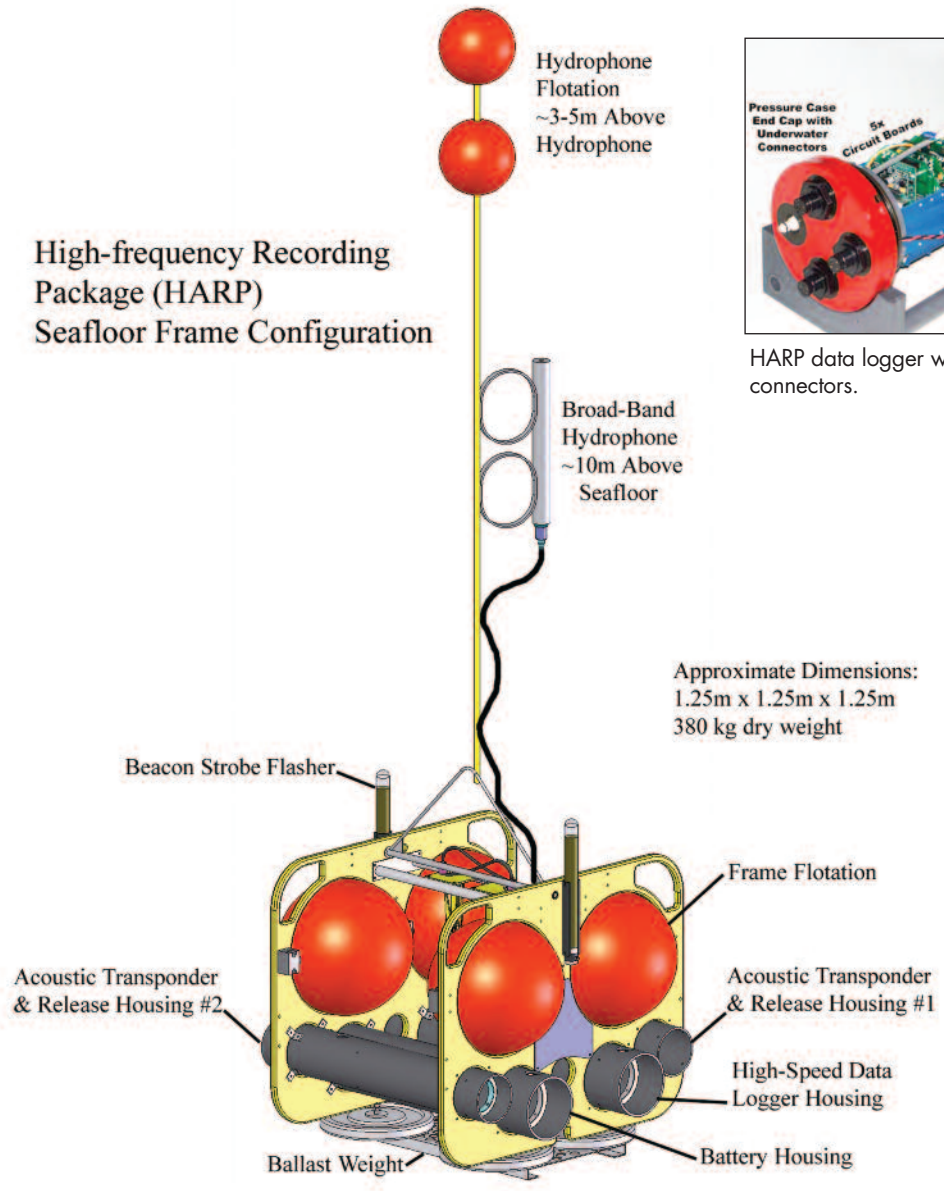
Technology Demonstration for Fleet Passive Acoustic Monitoring

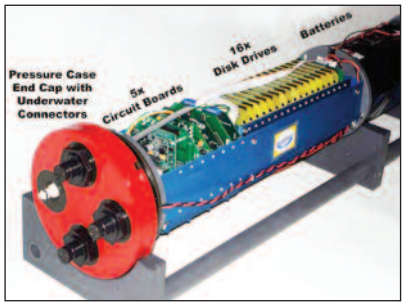
Principal Investigator: John Hildebrand
Project Status: Completed, Project 14-7

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

The challenge with using PAM to its fullest capacity lies in designing a system that will collect data at ample bandwidth (> 100 kHz) to detect all marine mammal sounds and with adequate data storage so that sensors may be deployed continuously with infrequent servicing.

This project focused on increasing the data storage capability of the HARP, currently used on several Navy ranges. This state-of-the-art recording system features high bandwidth (up to 160 kHz) combined with low power requirements. However, evolving mass storage capabilities have rendered the current HARP storage media obsolete.





HARP data logger with underwater connectors.

John Hildebrand, Sean Wiggins and colleagues at the Scripps Institution of Oceanography have developed the HARP for required Navy range acoustic monitoring. Under LMR program support, a new longer-lived, higher storage capacity HARP has been developed and demonstrated. New designs stand up to challenging deep-sea conditions and do not generate system noise that can interfere with recordings of animal sounds.

Upgrades of currently deployed HARPs for SATA disk storage capacity will yield reduced costs per deployment and potentially fewer service trips for sites that are difficult or expensive to access.

Earlier iterations of HARP data storage have been based on IDE (Integrated Drive Electronics), a standard electronic interface for disk storage devices. The American National Standards Institute's name for IDE is Advanced Technology Attachment or ATA. More recently the Serial ATA (SATA) interface has become the industry standard. Serial ATA offers several advantages over the parallel ATA interface, including reduced cable size and cost, and faster and more efficient data transfer. The IDE-based HARP system has a maximum storage capacity of 5 terabytes (TB) or 10 TB compressed storage. Installing the SATA interface is increasing storage capacity to 32 TB (64 TB compressed).

After the HARP electronic disk interface was designed, it was installed on a HARP system and tested, first at sea, and then on a Navy range. After a deployment of several months, data from the new system was analyzed, and performance was deemed acceptable. SATA drives have now been installed on all 13 existing Navy HARP systems. The new technology has also been applied to National Oceanic and Atmospheric Administration systems and other HARP systems.

Upgrades of currently deployed HARPs for SATA disk storage capacity will yield reduced costs per deployment and potentially fewer service trips for sites that are difficult or expensive to access. The SATA disk upgrade also is necessary to keep the HARPs currently being used for naval range monitoring serviceable because the IDE disks are no longer available.

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.

The guided-missile destroyer USS William P. Lawrence (DDG 110) at sea.
MCS2 Andrew P. Holmes

Funded Projects by Investment Area

This section presents ongoing and new LMR-funded projects by investment area. See the "Program Investment Areas" subsection in the "Program Overview" section (page 10) for descriptions.

INVESTMENT AREA 1: DATA TO SUPPORT RISK THRESHOLD CRITERIA

Conduct research regarding potential impacts to marine species from Navy training and testing activities, primarily focused on potential impacts from sound.

This investment area includes nine projects—four ongoing and five new start projects.

Ongoing

The Southern California Behavioral Response Study

Principal Investigators:
Brandon Southall and John Calambokidis
Project Status: Ongoing, Project 13-02

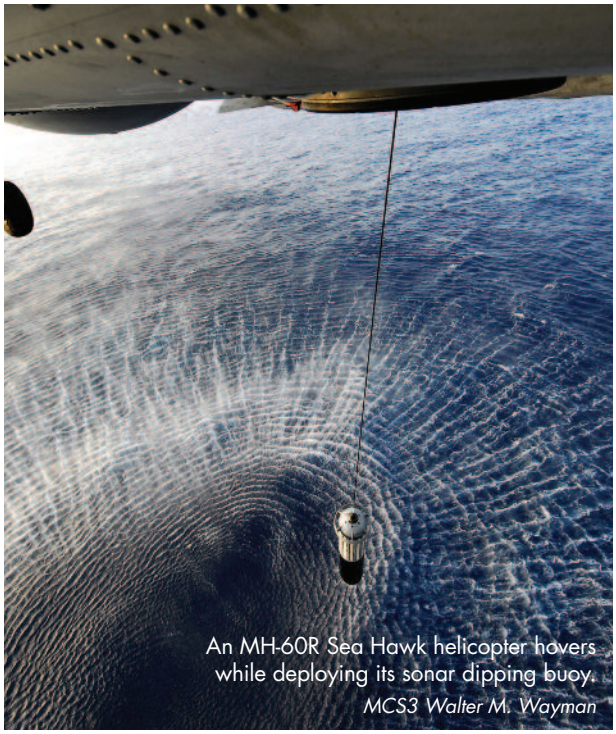
Need N-0011-13 Behavioral Responses of Marine Mammals to Navy Sound Sources

The Southern California Behavioral Response Study (SOCAL-BRS) is an interdisciplinary, multi-team, multi-year collaboration designed to increase understanding of marine mammal reactions to sound and provide a more robust scientific basis for estimating the effect of Navy MFAS on marine mammal behavior. High-resolution, multi-sensor tags allow direct measurements of potential behavioral responses using an experimental paradigm, providing results that are directly applicable to regulatory criteria and support the Navy's environmental compliance requirements.

This project built on and leveraged other Navy-funded research efforts, with field efforts occurring from 2010 through a final field season in 2016. The overarching approach has included a number of research objectives:

1. Tag a variety of cetacean species and obtain baseline behavioral data on species-typical behavior to support the interpretation of potential responses
2. Conduct controlled exposure experiments (CEE) to obtain high-resolution measurements of behavioral responses of marine mammals to MFAS
3. Apply adaptive team configurations to support both simulated MFAS sources and actual military MFAS sources in realistic exposure scenarios
4. Obtain basic biological, behavioral and foraging ecology data for marine mammals to support range monitoring efforts and/or habitat models.

Field teams collecting baseline behavioral data and conducting CEEs have included collaborators from various private, academic and government research organizations with wide-ranging expertise in a variety of monitoring, experimental and analytical disciplines. Personnel include visual observers, tagging teams, sound source engineers and fisheries acoustics biologists who conduct



An MH-60R Sea Hawk helicopter hovers while deploying its sonar dipping buoy.
MCS3 Walter M. Wayman

photo identification, PAM, geographical information system (GIS) tool application, acoustic modeling and advanced bio-statistical analysis.

Prior to CEEs, advanced movement and acoustic archival tags were deployed on focal animals using well-established safety and mitigation protocols authorized under research permits. Additionally, underwater acoustical monitoring (towed or drifting passive acoustic monitoring, fixed hydrophones on SCORE) was utilized, and visual observers monitored focal and other animals and determined if particularly vulnerable animals (e.g., neonate calves) were present. Sound exposure stimuli during CEEs were then presented within well-defined experimental and safety protocols from one of two source types. When possible in coordination with Navy training operations, these included actual Navy tactical sonar systems from surface ships or helicopter-dipping sonars. If such systems were unavailable, an experimental sound source was deployed from a research vessel and produced either MFAS waveforms similar to those of Navy tactical sonars to simulate actual systems, or pseudo-random mid-frequency noise as a comparison signal. All work was conducted within the terms of applicable federal and state permits, and 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.

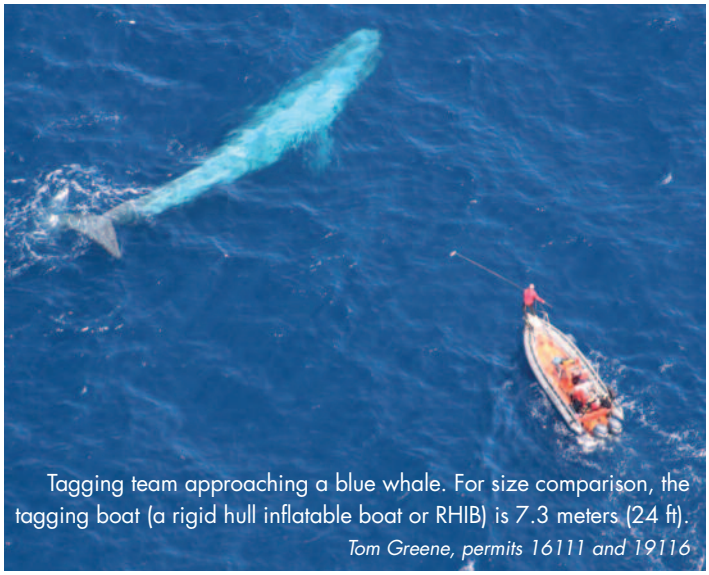
As new data were collected and analyzed, teams refined methodologies and experimental priorities as needed to reflect new knowledge, technology and opportunities. For example, utilizing smaller and faster boats improved tagging options, increased flexibility in scheduling and significantly reduced costs relative to previous methods.

Considerable effort within the Navy was made ahead of and during the final 2016 SOCAL-BRS research effort to ensure successful coordination with actual MFAS sources. This included both CEEs conducted with surface vessels and the successful novel integration of helicopter-dipping sonar systems used in realistic scenarios. Twenty-one marine mammals of three focal species were tagged during SOCAL-16, using both digital acoustic recording tags (DTAG)—

The SOCAL-BRS is working directly with the Navy to transfer these behavioral response findings into ongoing environmental assessment and compliance processes

which have been the main archival acoustic tag—and medium-duration acoustic tags. The medium-duration tags (a modified version of the Acousonde developed for longer deployments by Cascadia Research) supported weeks-long deployments and enabled analysis of response within a longer behavioral context than previously possible.

SOCAL-16 also included coordination with Southwest Fisheries Science Center towed PAM sensors to locate focal whales and with ONR-supported researchers who measured prey distribution around feeding baleen whales for use as a key contextual variable in analyzing whale behavior and response. A significant amount of new baseline data were collected during 2016, including the weeks-long records of behavior, acoustics and spatial movement of whales.



Tagging team approaching a blue whale. For size comparison, the tagging boat (a rigid hull inflatable boat or RHIB) is 7.3 meters (24 ft).
Tom Greene, permits 16111 and 19116

SOCAL-BRS is providing the Navy, and the broader marine mammal community through published and open-access results, detailed baseline data on movement and acoustic behavior of cetacean species as well as individual high-resolution measurements of behavioral changes during exposure. To date that has included baseline and CEE data on more than 180 individuals of ten federally protected marine mammals, including two beaked whale species and four endangered species (blue, fin, humpback and sperm whales). All of these data represent novel measurements for these species and some (e.g., Baird's beaked whales) represent the only available high-resolution movement and acoustic data. Key results to date include:

1. Responses to sonar varied by species. Beaked whales showed some of the clearest and strongest responses, whereas other demonstrated some clear responses, but with more variability and most strongly in particular conditions.

2. For blue whales where a large sample size during CEEs was achieved (n=52), responses are strongly dependent on behavioral context with deep feeding animals more likely to respond then shallow feeding or non-feeding animals. Inclusion of information on prey gave greater sensitivity in detecting this response.

3. Across species, responses appeared to be greater to the scaled sound source simulating MFAS at close range than to distant real Navy ships even at similar received levels. This indicates that spatial proximity of sound source is also contextually important and predictions based solely on received level are missing a key variable.

These findings, demonstrating the importance of these key contextual covariates in mediating behavioral response, have implications for the Navy beyond these specific species and the SOCAL operational area. While additional data are needed, they can and should increasingly be integrated into sonar response analyses to improve their precision and defensibility. The SOCAL-BRS is working directly with the Navy to transfer these behavioral response findings into ongoing environmental assessment and compliance processes, specifically the Navy's behavioral response assessment for Phase III and in support of the Navy's training range permit applications. The methods and tools that have been demonstrated during the project are being transitioned to the Navy's monitoring program.

Twenty peer-reviewed publications of baseline and CEE results to date (five within 2016) have been produced by SOCAL-BRS, with at least nine more currently in review or preparation for publication by the end of the project. Please see the LMR Publications section at the end of this report for additional details. Additionally, over 150 open presentations have been given by SOCAL-BRS team members at scientific and technical meetings as well as general public audiences at aquariums, museums and various schools.

Final data analysis across the entire SOCAL-BRS project, including the 2016 results, and final reporting will be completed during 2017, as well as completion of the publications in progress.

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. From 2003 to 2009, Southall was a fisheries research biologist and director of 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.

Key collaborators include 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).

Primary Audiograms of Hearing in Baleen Whales

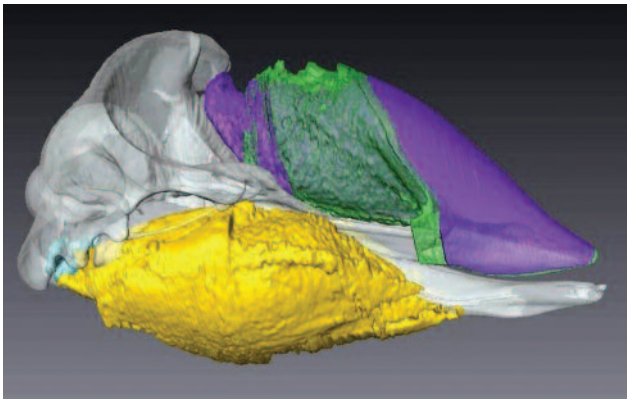
Principal Investigator: Darlene Ketten
Project Status: Ongoing, Project 15-11

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

The level of impact on marine mammals associated with active sonar and underwater detonations is difficult to determine without a solid understanding of how these animals hear and the relative effects of sounds at different frequencies on each species. Approaches to developing this understanding often involve direct measurements of auditory evoked potentials (AEP) or analyzing behavioral response to sound to develop audiograms. This project is pursuing an alternative approach to determining hearing that is especially useful in rare and large species of marine mammals such as beaked whales and baleen whales.

The project is focused on two components. First is defining how sound travels within the auditory systems of beaked and baleen whales, both on and below the water surface. The second component is to use this information to produce a model audiogram (a graphic representation) depicting the standard threshold for hearing frequencies in these animals.

The team uses ultra-high resolution computerized tomography (CT) scans to measure tissue architectures in 3D, and combines these data with neuroanatomical data from existing histology cases and measures of elasticity and stiffness of middle and inner ear components. The specimens are obtained from both archived ears from past studies and recent strandings.



Three-dimensional reconstruction of the melon (purple), jaw fats (gold) and skull (white) from CT scans of a Cuvier's beaked whale (*Ziphius cavirostris*).
Darlene Ketten

> The model audiograms will aid in species-specific risk assessments for hearing impacts...

The team will generate a model audiogram for baleen whales. The audiograms will aid in species-specific risk assessments for hearing impacts and will provide ear and head anatomical guides that support effective electrode and sound source placements for proposed auditory brainstem response (ABR) measures. The data will provide a scientifically valid risk assessment of susceptibility to hearing loss for those species based on measures of auditory system dynamic properties. It will also aid understanding of tissue responses under hyperbaric conditions.

Project results are expected to be published in 2017.

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.

Behavioral Audiometry in Multiple Killer Whales

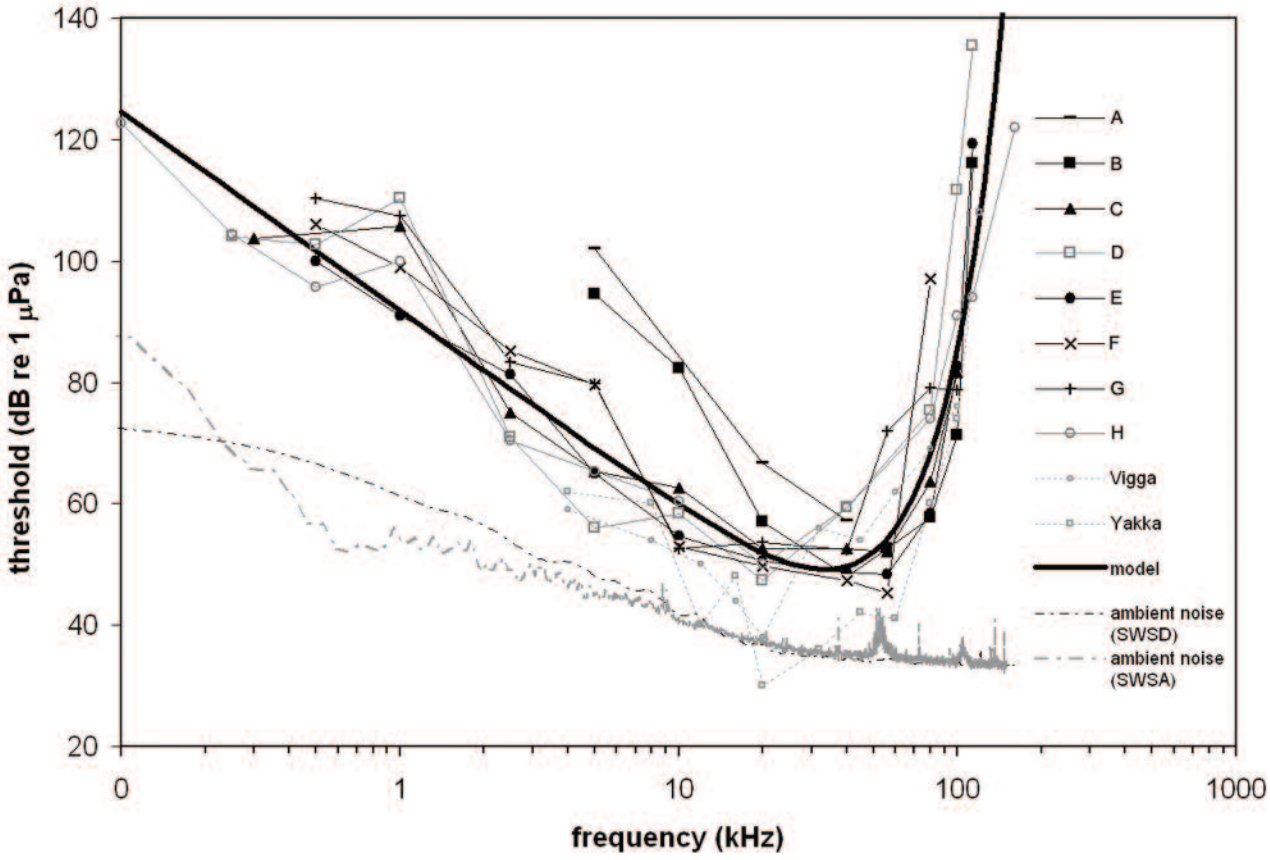
Principal Investigator: Brian Branstetter
Project Status: Ongoing, Project 15-14

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

To understand whether sound from naval activities is affecting hearing in marine mammals, it is necessary to understand the natural or baseline hearing in these mammals. 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 included five males and three females.

Prior to the start of this project, knowledge about killer whale hearing was based upon audiograms collected in the 1970s and 1990s, from only three killer whales. The whales tested consisted of two adult females and one sub-adult 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.

In this project, audiograms were measured using well-established psychoacoustic methods that are regularly employed by the National Marine Mammal Foundation (NMMF) for the testing of hearing in dolphins. Psychophysical hearing tests require trained animals, and are the "gold standard" of hearing tests, leading to the most accurate audiometric measurements. This project is follow-on work from a 2014 cooperative project between



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.

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 contribution to a composite hearing data set for killer whales has extended hearing thresholds for this species by measuring hearing thresholds 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 approximately 34 kHz, good hearing (i.e., within 20 dB of best sensitivity) from 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 four different odontocete species in 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. These data may be useful in predicting hearing abilities of other odontocete species for which data are sparse or lacking.

The final results, which will be published in the *Journal of the Acoustical Society of America* in 2017, will help to determine accurate mid-frequency cetacean composite audiograms and weighting functions for Navy at-sea environmental compliance.

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.

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

Principal Investigator: Ron Kastelein
Project Status: Ongoing, Project 15-20

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

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, acute hearing and functional hearing over a very wide frequency range.

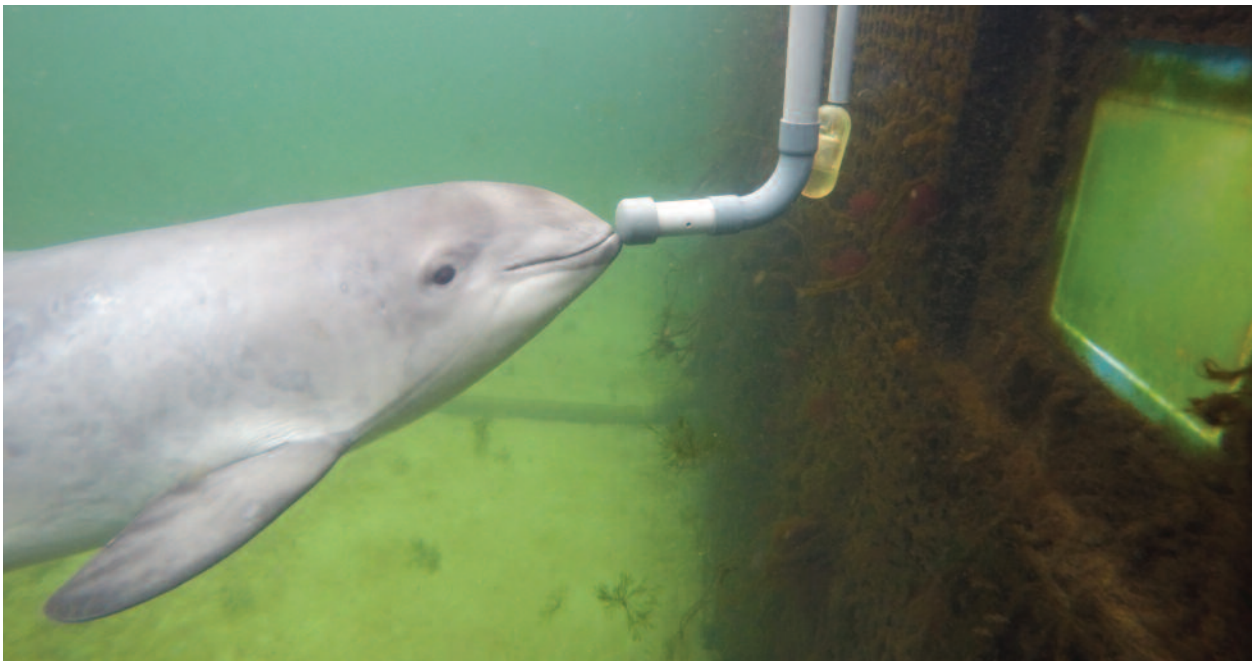
The results of the behavioral dose-response and TTS studies will be used to update the criteria and thresholds for harbor porpoises.

It is important to understand the difference between an animal hearing a sound and that sound causing an effect. Such effects can include either a behavioral effect or a physiological effect on hearing, known as a temporary threshold shift (TTS) or permanent threshold shift. Based on the limited amount of currently available information for harbor porpoises, predictions of TTS or behavioral response are derived from surrogate, mid-frequency cetacean species exposed to other sound sources (e.g., airguns). The resulting criteria might be inappropriate for harbor porpoises. More accurate data might result in reduced mitigation zones allowing for cost savings and improved training and testing opportunities.

This project consists of two study types: a behavioral dose-response study and a TTS study.

The behavioral dose-response study consists of two phases:

1. Establish the dose-behavioral response relationship for playbacks of 53-C sonar sounds at two duty cycles (2.6 and 90 percent) in quiet conditions.



A harbor porpoise at a listening station during hearing threshold assessment at SEAMARCO.
Dominic Dijkstra

2. Establish the dose-behavioral response relationship for playbacks of 53-C sonar sounds at 90 percent duty cycle in three Sea State noise conditions (Sea States 0, 4, 6, 8 and 10).

By the end of 2016, data have been collected for both of these phases. 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 2.6 percent at the highest sound pressure level possible without causing unwanted harmonics. Data from phase 2 are currently being analyzed.

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 at 90 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 2.6 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.

The first TTS study involved exposing the animals to 53-C sonar through an underwater transducer. The equal TTS over the entire hearing range study is scheduled to begin in beginning of February 2017.

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).

New Starts

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

Principal Investigator: Aran Mooney
Project Status: New Start, Project 16-22

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

The Navy is responsible for implementing a marine species monitoring program to assess potential impacts from Fleet and Systems Command military readiness activities involving active sonar and the use of explosives and explosive munitions. Some of these 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. Sound, both in-air and underwater, has the potential to affect marbled murrelets in Navy training and testing areas. Potential effects from sound might include auditory impacts such as temporary and permanent hearing threshold shifts as well as non-physical behavioral effects.

These basic data will provide both key hearing data needed for defining acoustic criteria for the marbled murrelet and refine the Navy's assessment of potential impacts from training and testing activities.

Currently there are no basic data on the hearing of marbled murrelets or any other Auk species, thus limiting predictions of the frequencies or sound levels that would actually induce effects. Lacking the information needed to predict with any certainty the appropriate criteria for evaluating the onset of behavioral change or injury in the marbled murrelet, the U.S. Navy has had to use criteria for other species as a surrogate to predict effects.

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

This project will define 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. Efforts will include comparative in-air physiological and behavioral audiometry tests to outline the frequencies and sound levels to be used in the underwater tests, as well as to help ground-truth the underwater data and address potential Auk underwater auditory adaptations. The resulting audiograms will provide the data and training foundation for a TTS response feasibility study.

These basic data will provide key hearing data needed for defining acoustic criteria for the marbled murrelet. More accurate acoustic criteria could improve Navy impact assessments and result in more realistic mitigation zones around activities that include sonar, explosives and pile-driving.

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.

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

Principal Investigators:
Greg Schorr and Erin Falcone
Project Status: New Start, Project 16-23

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

To begin to understand marine mammal behavioral responses to Navy activities, researchers use behavioral and acoustic monitoring methods that can include field observations, controlled exposure experiments (CEE), fixed range hydrophones and other PAM equipment such as monitoring tags. The monitoring tags used during most CEEs to date have relied on high-resolution but short-duration archival tags. To expand the Navy's understanding of behavioral responses, longer-duration monitoring tags that can collect more high-resolution data need to be deployed.

The project team will deploy longer-duration, high-resolution behavior recording tags on Cuvier's beaked whales (*Ziphius cavirostris*) and ESA-listed fin whales (*Balaenoptera physalus*) around actual Navy exercises on SCORE. The efforts will document the behavior of these two species before, during and after actual Navy exercises, with a goal of recording sufficient individual baseline data. This will increase the sample of high-resolution data during MFAS exposures from multiple platforms (e.g., ships, helicopters) across a range of distances.

In the analysis phase, the team will combine whale movements and diving behavior from tags, tracks from ships

The effort will generate significantly larger samples of high-resolution behavioral data...particularly for beaked whales.

An MH-60R Sea Hawk helicopter hovers with its sonar dipping buoy lowered in front of the aircraft carrier USS John C. Stennis (CVN 74).
MCS3 Josue L. Escobosa

and helicopters participating in exercises supported by SCORE or Pacific Fleet, and archived acoustic data from the range hydrophones and/or acoustic recording tags in a unified framework. Bringing these pieces together 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 vessel, and duration, pattern or frequency of exposure.

The effort will 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 18 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 from the Naval Undersea Warfare Center, Stacy DeRuiter from Calvin College, and 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: James Finneran
Project Status: New Start, Project 16-24

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

The Navy needs data on potential hearing effects from military readiness activities, such as active sonar and underwater detonations from explosives, to ensure that it complies with regulatory criteria. Navy acoustic impact analyses currently used in the regulatory and permitting process 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. 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 data resulting from the proposed effort will be used to define the Navy Phase IV weighting function and TTS/PTS threshold values for the mid-frequency cetacean group.

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 methods.

Bottlenose dolphins.
Mark H. Deakos, permit 14451

Hearing thresholds in bottlenose dolphins will be measured using both behavioral and electrophysiological auditory evoked potential (AEP) methods. Researchers will 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 will be continuously monitored and managed by attending veterinarians and animal care staff at the Space and Naval Warfare Systems Center Pacific.

The data resulting from the proposed effort will be used to define the Navy Phase IV 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.

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.

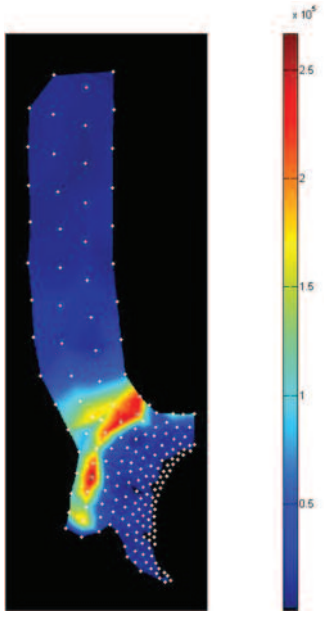
A Blainville's Beaked Whale Behavioral Risk Function for Hawaiian Populations

Principal Investigators: David Moretti, Len Thomas and Elizabeth Henderson
Project Status: New Start, Project 16-25

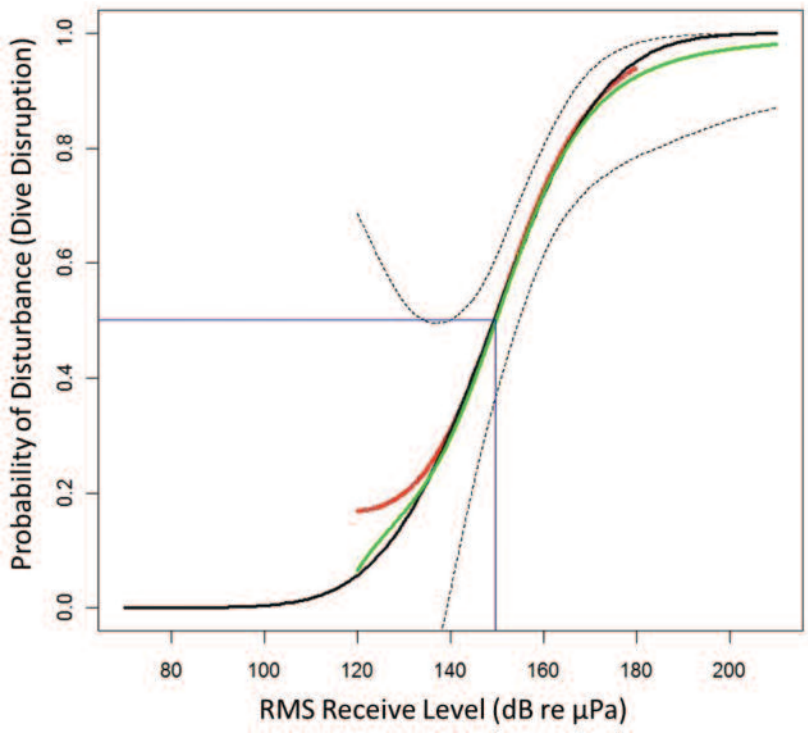
Need N-0102-16 Behavioral Response Research to Study the Effects of Sound on Marine Mammals

As part of the permitting process arising from a suite of federal environmental laws and regulations that apply to marine mammals, Navy planners use behavioral risk functions to estimate how marine mammals, and particularly beaked whales, respond to real world sonar exposure situations. For its Phase III Environmental Impact Statement (EIS) analyses, the Navy used behavioral risk functions developed for Blainville's beaked whales at AUTEC. This species also has been found on the Pacific Missile Range Facility (PMRF) undersea acoustic range. The Navy needs to determine the appropriate behavioral risk function for the Hawaiian populations of this species.

The primary goal of this effort is to publish the first behavioral risk function for the Blainville's beaked whale (*Mesoplodon densirostris*) in Hawaii at PMRF, which then can be used to inform future NMFS compliance decisions. 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 will



Distribution of Md Click Counts on PMRF, July 2012.



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.

adapt the methods used at AUTEC to animals detected on the PMRF range and demonstrate how the methodology can be used in different locations.

The team will begin by applying available PMRF data, using the method developed for AUTEC, to evaluate how well the data fit the AUTEC model and to identify additional data needs. Following a Submarine Command Course on PMRF, the team will apply the additional data to a refined statistical model to derive a PMRF Blainville's beaked whale risk function. The behavioral risk function will be based on real 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 primary goal of this effort is to publish the first behavioral risk function for the Blainville's beaked whale in Hawaii.

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 Command. She focuses on bioacoustic and noise impact analyses for environmental compliance.

The Effects of Underwater Explosions on Fish

Principal Investigator: Peter Dahl
Project Status: New Start, Project 16-26

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

U.S. Navy Explosive Ordnance Disposal (EOD) team training activities can include underwater explosive charges, and additional data are needed regarding the effects of such explosives on fish. The existing data on which criteria are based are decades old and do not address all the metrics and fish types needed. In order to quantify potential impacts to threatened and endangered species of fish, there is a need for data related to sizes, depths, and distances to the subjects that are relevant to Navy explosives training activities.

A multidisciplinary team of researchers and Navy EOD technicians will conduct field-based experiments to collect data needed to develop guidelines and threshold criteria for effects on fish resulting from exposure to underwater explosives. The results will help to predict potential effects that may occur during Navy training activities.

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.

The team's approach will provide a broader and more comprehensive understanding of potential effects and dose-response relationships. The results of the proposed applied research and accompanying derived criteria will be immediately useful for Navy environmental compliance when quantifying potential explosive impacts to fish and habitat.

> The results...and accompanying derived criteria will be immediately useful for Navy environmental compliance when quantifying potential explosive impacts to fish and habitat.

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.

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

INVESTMENT AREA 2: IMPROVED COLLECTION AND PROCESSING OF PROTECTED SPECIES DATA IN AREAS OF NAVY INTEREST

Develop methods to improve the ability to process large amounts of marine species data and provide cost-effective solutions to enhance marine species monitoring capabilities.

This investment area includes five ongoing projects. No new projects were funded in this investment area during 2016.

Ongoing

Simple Performance-characterized Automatic Detection of Marine Mammal Sounds

Principal Investigator: David Mellinger
Project Status: Ongoing, Project 14-3

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

This project team is creating a database of performance-characterized detectors/classifiers for many marine mammal species that can be integrated into the current PAM software package, Ishmael.

The Ishmael program, originally developed by Dave Mellinger with funding from the National Oceanic and Atmospheric Administration (NOAA) and ONR, is one of the most popular bioacoustics programs used in the field today, and has been recently upgraded. It includes displays of sound waveforms and spectrograms, recording capability for real-time input, and several methods for acoustic localization and automatic call recognition.

Detectors/classifiers, in the form of Ishmael configuration files, were added to an online archive. They are characterized and evaluated by testing them against sound files found in MobySound.org, a publicly accessible archive of sound recordings of over 35 marine mammal species. 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. This broader, deeper and easier-to-use signal processing system will enable any Ishmael user to detect sounds coming from a species or subspecies of interest in a specific area.

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

Progress to date includes adding seven online detectors to Ismael: beaked, sperm and baleen whales. These detectors/classifiers have been tested against the sound files in MobySound to provide performance information for each one in the form of receiver operating characteristic and detection error tradeoff curves.

Additional completed work includes extensive revisions to the Ishmael user's guide and development of an Ishmael tuto-

rial for new users. Information on the package will be part of a presentation in a 2017 stand-alone training workshop. The workshop will be for Navy personnel and private (contractor) marine mammal observers as well as regulators who are involved in Navy passive acoustic data. Training materials also will be presented as a module in the Passive Acoustic Technology training course conducted by Bio-Waves, Inc.

> An automated system for detecting marine mammals...will reduce the need for manual review, ultimately reducing Navy monitoring costs.

When this new software is integrated into Ishmael, a relatively naive user will be able to sit down, choose what species to monitor, and the system will provide detections and other performance measures for those species.

An automated system for detecting marine mammals that is both straightforward to use and well-characterized offers multiple benefits. By providing faster and easier analysis of acoustic data, it will promote widespread use within the Navy's monitoring program and scientific community. More widespread use will make review of acoustic data more straightforward and reduce the need for manual review, ultimately reducing 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.

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

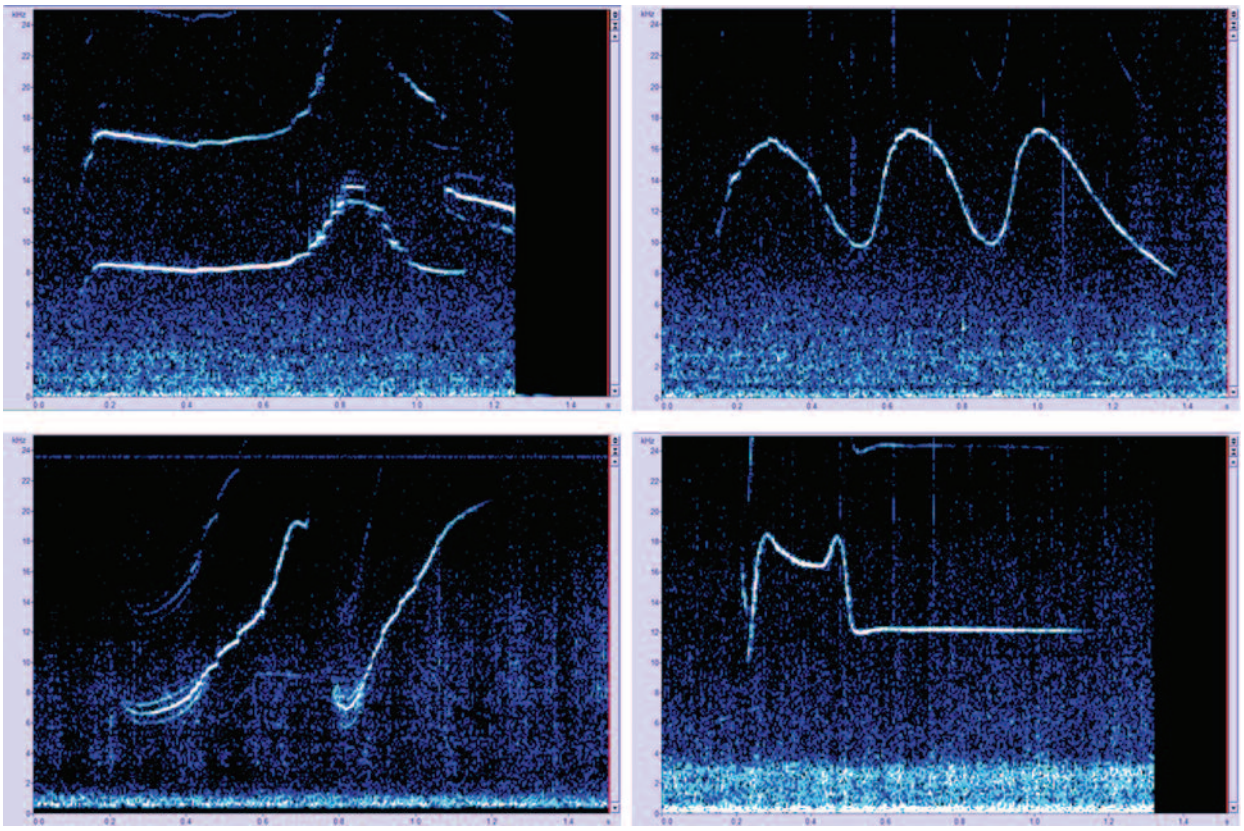
Principal Investigators:
Julie Oswald and Tina Yack
Project Status: Ongoing, Project 14-5

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

This project is working to advance the science of automatic classification by developing a suite of fully automated click feature extraction tools and classifiers for odontocete species in the northwest Atlantic Ocean, the temperate Pacific Ocean and the waters surrounding Hawaii. These classifiers combine information from whistles, clicks and the acoustic behavior of schools to identify the sounds produced by odontocetes.

The variability inherent in many sounds produced by odontocetes makes 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. As such, combining information from different types of sounds may provide more power for identifying species than classification based on only one sound type at a time. Therefore, an automated classifier that includes information from both whistles and clicks as well as other contextual information (e.g., location, number of whistles, number of clicks, overlap among sounds, etc.) would advance the science of automated classification.

The project team is developing classifiers that use information from both whistles and clicks as well as variables related to geographic location and acoustic behavior to classify acoustic encounters with odontocete species on several naval ranges. These classifiers have been incorporated into 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



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

PAMGuard. The classifiers will be made available for use in another widely used software package called Ishmael. Both of these software packages are freely available to all users.

Three geographic classifiers will be available at the end of the project: one for odontocete species in the waters surrounding the Hawaiian Islands, a second for species in the northwestern Atlantic Ocean (both areas funded by ONR), and a third for species in the temperate Pacific Ocean (funded by the LMR program).

In fiscal year 2016 (FY16), training of automated classifiers for all three locations was completed and integrated into PAMGuard software. In 2017 they will integrate the classifiers into Ishmael software. Three manuscripts will also be produced within the ONR project, one examining geographic variation in whistles, one examining geographic variation in clicks and one describing the classification approach and results. The classifier will be presented at the European Association for Aquatic Mammals conference in Genoa, Italy in March 2017.

Combining whistle, click and context feature vectors to produce a final classification will provide a tool for efficiently and automatically processing the large data sets generated during PAM projects. It will improve the Navy's ability to characterize the presence and abundance of odontocetes, by species, within training and testing

Combining whistle, click and context feature vectors will improve the Navy's ability to characterize the presence and abundance of odontocetes, by species, within training and testing areas and reduce costs of manual reviews.

areas and reduce costs of manual reviews. User manuals and updated help files will be produced and made available to users on the Bio-Waves and LMR 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 bio-acoustic data, developing tools for PAM, and providing assessments of the effects of noise on the marine environment. Dr. Oswald has a Ph.D. in Oceanography from the 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.

Bottlenose dolphins.

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

Principal Investigator: Shannon Rankin
Project Status: Ongoing, Project 15-16

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

This goal of this project is to develop an alternative approach to density estimates of baleen whales by defining a correction factor that could be used to convert call density data to whale density. The concept is to develop a correction factor using data collected during combined visual and acoustic shipboard studies. In this approach, the visual sightings are used to establish a "known" density estimate, and passive acoustic monitoring of sonobuoys provides us with the density of calls (number of calls per unit area per unit time) for the same area. The correction factor that translates the call density to whale density for these surveys can then, in theory, be applied towards novel sonobuoy data collected in an area of interest to the Navy. This pilot project is specific to the California Current and Navy's SCORE range.

This project investigates using sonobuoys as an alternative approach to whale density estimation.

In phase one, the project team members participated in a larger marine mammal survey in 2014, which was conducted by NOAA. This survey—with funding from NOAA, the Bureau of Ocean Energy Management and Navy—consisted of visual line-transect survey methods during daylight hours to estimate the total density of whales in the study area. Concurrently, evening sonobuoy stations provided an opportunity to estimate whale calling density for the same study area. Each evening sonobuoy station consisted of two sonobuoys deployed at a distance of one nautical mile from each other. A total of 215 sonobuoys were deployed systematically, as well as opportunistically when baleen whales were sighted. The sonobuoys used

On board ship, monitoring signals from the deployed sonobuoys.

were equipped with signal processing technology that works in conjunction with PAMGuard, a widely used marine mammal passive acoustic processing program. Experienced acoustic technicians detected and localized specific stereotyped baleen whale calls, providing an estimate of the call density for each sonobuoy station. Critical to this approach was the estimated range of the calling animal to the sonobuoy station. The known whale density provided by visual line-transect survey methods was compared with the call density for blue and fin whale calls.

Team members conducted a playback experiment during a 2016 sea trial to examine factors that affect the accuracy, precision and bias in sonobuoy localization. The experiment provided over 1,200 location estimations for analysis. Several sources of error were identified, including:

- Calibration precision varied according to calibration methods
- Gain imbalance in vector sensors led to bias in angle errors according to compass bearing
- Sonobuoy drift affected range estimation to sound sources.

Calibration methods have been identified that will address these issues and will be recommended for future data collection. Each sonobuoy may have individual variation that can affect the angle estimation, and the DIFAR (Directional Frequency Analysis and Recording) module in PAMGuard has an automated approach to individual buoy correction using vessel noise. Alternatives to calibration noise via ship noise must be considered for application on new quiet vessels. Localization error can be improved through modeling various sources of error and application of this error model to data. Finally, the intended approach to call density estimation (point transect distance sampling methods) is likely inappropriate for these methods. Alternative methods for estimating call density should be considered.

The final phase of this project (FY17) will include development of a protocol for data collection and analysis that will address lessons learned during this study. This will include a software package that will allow for compilation of data and application of localization error models. An alternative approach to call density estimation has been identified (spatially explicit capture-recapture methods), and will be tested using data collected during this study.

This project investigates using sonobuoys as an alternative approach to whale density estimation. The Navy's supply of sonobuoys could make it possible to initiate data collection for estimating call density on relatively short notice. Data collection can be conducted in real-time, allowing for a short turnaround between identifying a need and obtaining data and call density estimates for baleen whales in a given area. The software provided by this study will allow for standardized data collection and analysis, and will provide an estimate of localization error. These and other features within the open-source software will further benefit researchers using Navy sonobuoys for marine mammal research.

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 15-17

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

While the Navy uses PAM data for many environmental monitoring purposes, the ability to derive improved density estimates for species of concern is a powerful and beneficial application of PAM. However, methods for using PAM for density estimates need to be developed and refined.

The project is developing spatially and temporally explicit density estimates for blue and fin whales in the SOCAL range to provide the Navy with a realistic, quantitative assessment of levels of impact. The project team is leveraging results from work completed under ONR funding, utilizing data from acoustic tag deployments from the SOCAL-BRS, and other tagging studies in the area and will perform additional acoustic tag data collection, using newly available long-term tags. Results will ensure better estimates of potential disturbance and harassment for future naval training and Environmental Impact Statement (EIS) assessments. The project will transition previous work conducted under ONR sponsorship.

The project is developing spatially and temporally explicit density estimates for blue and fin whales in the SOCAL range to provide the Navy with a realistic, quantitative assessment of levels of impact.

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.

Brandon Southall, Ari Friedlaender and John Calambokidis dual deploy an acoustic and video tag on a blue whale as part of the SOCAL Behavioral Response Study in July 2014. Acoustic tag data from the SOCAL-BRS will be used as part of this study.

A. Allen, NMFS Permit 14534

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

Principal Investigator: Len Thomas
Project Status: Ongoing, Project 15-19

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

Much of the PAM-based density estimation work is now taking place on Navy testing ranges where there are pre-existing arrays of cabled hydrophones. However, because a large amount of the Navy's activity takes place away from these instrumented ranges, methods applicable to such non-instrumented areas need to be fully developed, demonstrated and validated.

This project will 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, 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 will employ data and systems from both the SOCAL BRS and the M3R projects—the former to give information about acoustic behavior and the latter to allow validation of findings from the retrievable array.

In FY16 the project team began the acoustic array design. The design will be finalized in FY17, following a test deployment and analysis of the resulting data. The full array will be deployed in the subsequent year.

The project will produce density estimates and associated animal distribution maps that combine data from both instrumented and non-instrumented ranges. Density estimates will be added to the Navy Marine Species Density Data archive.

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.

Cuvier's beaked whale.
Brenda K. Rone, permit 15330

INVESTMENT AREA 3: MONITORING TECHNOLOGY DEMONSTRATIONS

Demonstrate technologies that offer to enhance marine species monitoring capabilities.

This investment area includes four projects: two ongoing and two new start projects.

Ongoing

Demonstration of High-performance PAM Glider and Profiler Float

Principal Investigator: Haruyoshi Matsumoto
Project Status: Ongoing, Project 14-4

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

This project demonstrated two autonomous PAM platforms based on commercially available gliders and floats. Both platforms incorporated a signal processing system developed by Oregon State University with funding from ONR.

This project team demonstrated marine mammal monitoring capability of an APEX-based float known as QUEphone, and the Seaglider from Kongsberg. The intent was to compare the marine mammal monitoring capabilities of these platforms to those of a bottom-moored HARP at the Quinault Training Range (QUTR) in Washington State, and to the M3R system at SCORE.

Both the float and the glider are buoyancy-driven, deep-diving vehicles capable of descending to 1,000 meters (glider) and 2,000 meters (float). This capability can result in increased beaked whale detection, and it is hoped that these platforms can contribute to a more robust acoustic data set for these animals.

While gliders can be steered remotely, profiler 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.

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.

The two platforms were tested first at the QUTR 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 bottom-mounted hydrophones were not working during the testing period on this range, so no comparison was made. In the second year, the Seaglider and float were tested at the SCORE range 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 per-

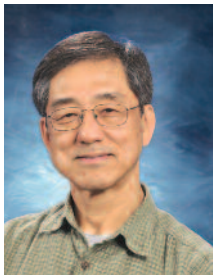
formance indicated that when the Seaglider was moving fast, flow noise affected the performance of detecting baleen whales. System electronics noises, however, did not appear to affect the detection performance on either platform. Subsequently, the float and glider were deployed in an ONR-funded project off the coast of Santa Catalina Island. As this is a HARP-instrumented seafloor area, comparisons are being made between the data gathered by both mobile platforms against the bottom-mounted system.

Reliable acoustic AUV technology will enable efficient, cost-effective marine mammal monitoring inside or outside of instrumented U.S. Navy ranges...

Reliable acoustic autonomous underwater vehicle (AUV) technology will enable efficient, cost-effective marine mammal monitoring inside or outside of instrumented U.S. Navy ranges or when poor weather conditions prohibit ship-based visual observation. 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.

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.



Integrated Real-time Autonomous PAM System

Principal Investigators:
Philip Abbot and Vince Premus
Project Status: Ongoing, Project 14-12

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

To address the U.S. Navy's need for persistent autonomous monitoring, either on or off at-sea training ranges, this project demonstrates the potential for a powered AUV, equipped with a passive acoustic sensor array, to provide reduced-cost and improved acoustic monitoring and survey capabilities.

The integration and demonstration of passive sonar hydrophone arrays into autonomous undersea platforms for acoustic marine mammal monitoring has witnessed significant advances in the last few years due to the availability and scalability of low-cost, low-power commercial technology for acoustic remote sensing. 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 (DCLT) of baleen whales and odontocetes. The system, known as the Integrated Real-time Autonomous Passive Acoustic Monitoring System (IRAP), offers significant 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 DSP 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.

REMUS being deployed during a technology test.
Mandy Shoemaker

The project includes integrating sensors and DCLT software into an embedded low power processor, then demonstrating the technology through end-to-end engineering tests and at-sea marine mammal surveys to validate the system. 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.

This project demonstrates the potential for a powered autonomous underwater vehicle... to provide reduced-cost and improved coverage of acoustic monitoring and survey capabilities.

During 2016, the real-time monitoring capabilities of the IRAP system were tested at PMRF off Kauai, in concert with the Submarine Command Course. OASIS 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.

Based on cues provided by the onshore M3R team listening to bottom-mounted hydrophones at PMRF, the OASIS team deployed the IRAP system in deep water about 20 nautical miles northwest of Kauai in the vicinity of foraging beaked whales. The result was the first-ever detection and tracking of natural beaked whale clicks on an AUV-based high-frequency array.

The sensor and processing technology comprising IRAP can be employed on other autonomous platforms as well. The project team provided an initial comparison of three possible alternatives: 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.) were detailed. Additional platform evaluation will be completed in 2017.

This technology could be used by 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.

New Starts

Extended Duration Acoustic Tagging of Right Whales

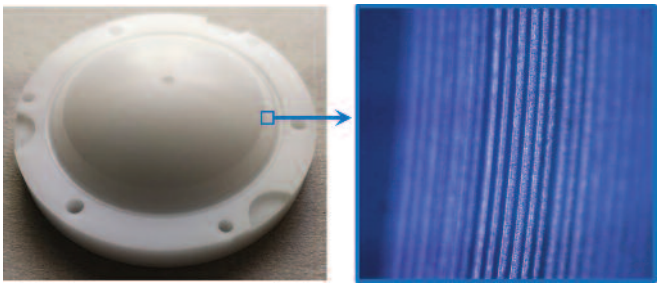
Principal Investigator: Susan Parks
Project Status: New Start, Project 16-21

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

To improve understanding of marine mammal behavior, researchers employ a variety of passive acoustic monitoring and recording techniques. Acoustic recording tags that can be non-invasively attached to an animal have provided baseline data on sound production for a wide range of critical marine mammal species. Earlier versions of these tags had limited recording capacity, ranging from 12 to 20 hours. An additional limitation has been their attachment mechanism, which typically limited data collection to less than one day. To improve its compliance assessment effort, the Navy needs finer-scale data of acoustics and marine mammal behavior that have been collected over longer time periods.

Expanding data collection from digital tags (DTAG) over longer durations requires not only tags that can record desired data points for longer periods, but also an attachment mechanism that will keep the tag attached for as long as possible. The latest generation of DTAG, the DTAG-3, offers significant data collection advancements with the potential to collect acoustic data for up to 72 hours from baleen whales. Tests of new micro-texture and glue attachment methods offer promising results for use with the new tags.

This study is the first to apply the newly developed attachment system to a free-ranging baleen whale.



Mold (left) used to produce micro texture (right) into the edge of the suctions cups.
A. Cannon

Researchers will 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.

This study is the first to apply the newly developed attachment system to a free-ranging baleen whale.

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 coastal 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.

High Fidelity Acoustic and Fine-scale Movement Tags

Principal Investigator: Alex Shorter
Project Status: New Start, Project 16-27

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

To improve understanding of marine mammal behavior in relation to Navy activities, researchers often use monitoring tags that, while attached to an animal, use sensors to measure animal movement and the sounds made and heard by the tagged animal. This information can then be used to infer several acoustic and behavioral activities. As the need for marine mammal monitoring has increased, researchers require new, readily available tags to collect fine-scale acoustic and movement information during acoustic response studies that are key to meeting the needs of the Navy.

> This project will subject the DTAG-3 design to rigorous field testing by multiple researchers on a range of animals.

The ONR Marine Mammal Biology program supports basic research on developing new and improving existing monitoring tag technology. After the tags resulting from such research have been sufficiently tested, they need to be field demonstrated, which falls within the mission of the LMR program. LMR-funded researchers can provide critical feedback on tag performance under field conditions, while concurrently collecting critical behavioral data.

This project will build 20 new (third) generation DTAGs (DTAG-3s), to be made available for upcoming behavioral response studies. These tags are highly integrated, compact, low-power, high-fidelity acoustic bio-logging tags that are well suited for studying both deep-diving beaked and large baleen whales. In designing the DTAG-3, designers have worked to reconcile lower cost and ease-of-manufacturing

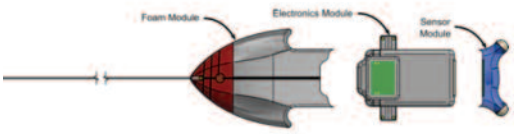


Illustration of the encapsulated DTAG-3 design.

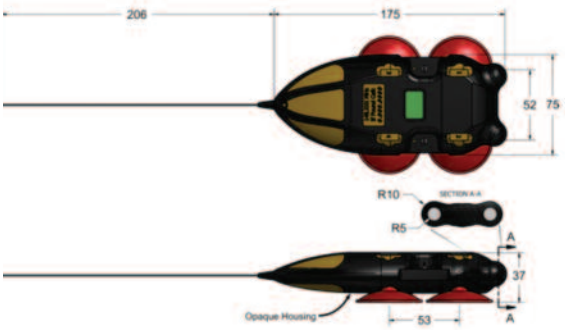


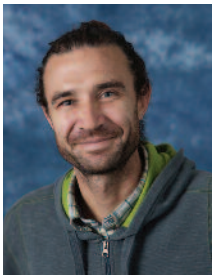
Illustration of the encapsulated DTAG-3 assembly with suction cups.

objectives with multiple field requirements including reduced size for small odontocetes, longer duration tag attachments and wider bandwidth recordings. To achieve these potentially conflicting requirements, a number of innovative features were introduced in the DTAG-3 design. This project will subject the DTAG-3 design to rigorous field testing by multiple researchers on a range of animals.

The researchers using the tags will demonstrate tag field reliability, and feedback from these deployments will be used to improve the design of future tags. In addition to field demonstrating an ONR-developed technology, the project will enable upcoming behavioral response studies by providing recording bandwidth, sensitivity and software support not available via other commercially available tags.

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 bio-logging tags. Dr. Shorter earned his Ph.D. in Mechanical Engineering from the University of Illinois at Urbana-Champaign.



INVESTMENT AREA 4: STANDARDS AND METRICS

Establish interagency and scientific community standards and metrics to evaluate marine species data to provide comparable results.

The projects currently within this investment area are addressing different aspects of data standards. There are five ongoing and one new start.

Ongoing

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

Principal Investigator: John Hildebrand
Project Status: Ongoing, Project 14-6

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

Because PAM systems can generate large quantities of data, processing this amount of data to find marine mammal calls is a difficult and time-consuming task. It also typically requires trained acoustic data technicians. The current state-of-the art for processing large PAM data sets is a hybrid between manual scanning of the data and automatic call detection. This hybrid approach allows accurate analysis of large data volumes and is the baseline against which the efficiency of automatic detection and classification algorithms must be compared.

This project's team is developing evaluation data sets and metrics for assessing the performance of existing and future data processing algorithms for PAM data. To do so, the team is constructing marine mammal sound data sets specific to a particular Navy training area, then composing a standardized set of metrics to assess the performance of both existing algorithms and potential new algorithms.

In FY16 the team completed work on an east coast data set 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 spp., 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.

Right whale.

The project team is developing evaluation data sets and metrics for assessing the performance of existing and future data processing algorithms for PAM data.

A parallel effort is engaging the marine mammal detection and classification community to develop a standardized set of metrics for evaluating automatic detector and classification outputs. A metrics committee, formed in FY15, worked through FY16 to address algorithm testing and other detection and classification issues. Work by the metrics committee will be universally applicable to both existing and potential new automatic detection algorithms for specific baleen whale calls and odontocete signals. New algorithms can be promulgated to all end-user PAM operators once they have been demonstrated to provide the necessary recall and precision for a particular species call.

The ultimate goal 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. Automated methods to detect and classify marine mammal sounds would simplify data analysis and reduce data processing costs.

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, the Scripps Institution of Oceanography; Marie Roch, San Diego State University.

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

Principal Investigator: Dorian Houser
Project Status: Ongoing, Project 15-13

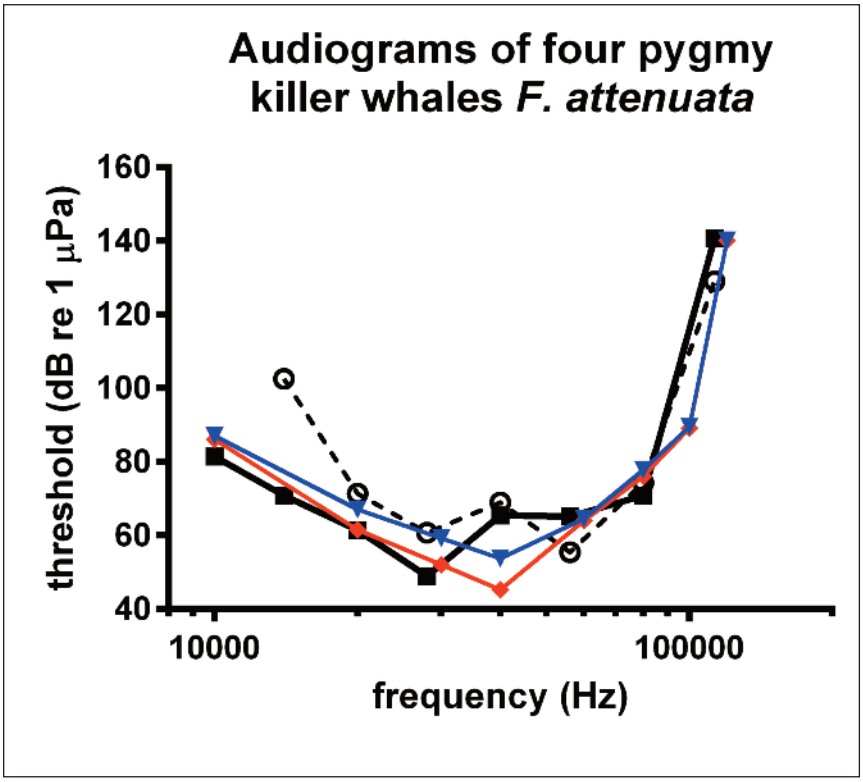
Need N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

To understand the natural or baseline hearing in marine mammals, researchers have measured hearing thresholds either by studying behavioral response to sound or by taking an electrophysiological approach. In the latter, they measure voltages produced by the brain in response to an acoustic stimulus. These voltages, termed auditory evoked potentials (AEP), can be quickly measured in subjects with minimal subject cooperation.

…standardized methods and increased sample sizes will help to reduce uncertainty in hearing range analyses used by Navy planners.

However, different AEP methodologies can result in large differences in threshold estimates for the same species, or even the same individual. Differences may 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.

This multifaceted project is working to standardize hearing threshold measurement methods used in odontocetes and to increase species representation and sample sizes in hearing threshold estimates. Such standardized methods and increased sample sizes will help to reduce uncertainty in hearing range analyses used by Navy planners.



Specific efforts include developing and promoting a standardized methodology for review and, ultimately, approval by the American National Standards Institute (ANSI). Once the ANSI standard is final, the portable AEP system currently in use, the Evoked Response Study Tool (EVREST), will be updated according to the consensus methodologies determined through the standardization process. Prior to standard completion and EVREST reprogramming, however, the project is maintaining existing portable EVREST systems for stranding networks and continuing to train stranding network personnel in AEP data collection.

During FY16 the project team made significant progress on developing a draft standard for AEP methods for odontocetes. The standards working group, which was formed during FY15 and includes subject matter experts in marine mammal audiometry and stakeholders in marine mammal noise issues, has reviewed and contributed to four drafts of a proposed standard. Results of the most recent working group discussions, held in conjunction with an Acoustical Society of America (ASA) meeting in November 2016, have been incorporated into a new working document. A final draft of the standard is expected to be delivered to the ASA Secretariat for consideration in 2017.

Stranding network trainings have been held annually, the most recent of which had four stranding response regions participate. 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. Approximately six people across the regions have been trained.

All EVREST systems belonging to the stranding networks were recalibrated and received maintenance at the training sessions. Once the AEP standard is completed, the EVERST systems will also be 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-one small cetaceans representing five species have had AEP hearing tests conducted on them by the primary investigator and stranding networks since the beginning of the project.

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 and Peter Krysl
Project Status: Ongoing, Project 15-15

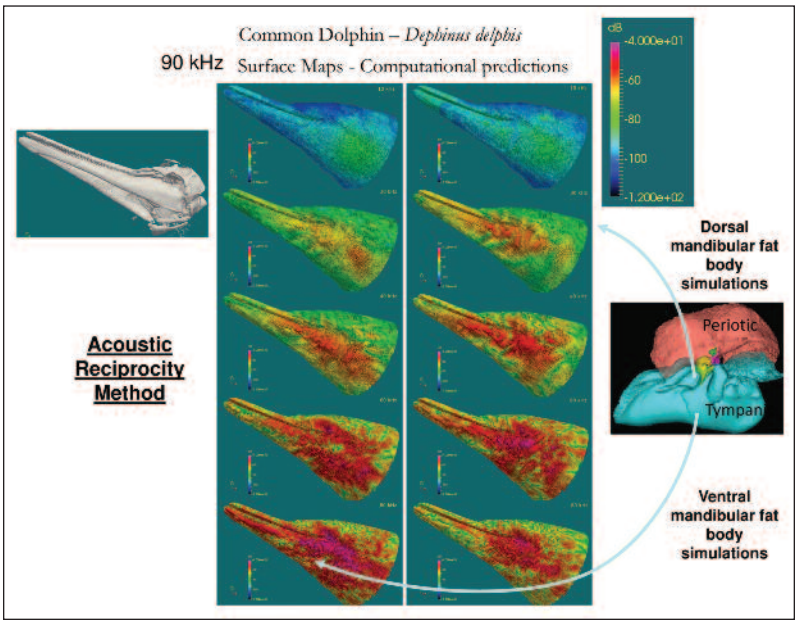
Need N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species

Understanding baseline hearing in marine mammals—how and what they hear—is an important component of the Navy's marine species monitoring and compliance efforts.

To understand the baseline hearing in marine mammals, researchers have measured hearing thresholds either by studying behavioral response to sound or by taking an electrophysiological approach. In the latter, they measure voltages produced by the brain in response to an acoustic stimulus. These voltages, or auditory evoked potentials (AEPs), can be quickly measured in subjects and do not rely on the extensive marine mammal behavioral training needed for behavioral response threshold measurements.

To deliver sound directly to an animal for AEP measurements, researchers use a device known as a jawphone (suction cup containing a transducer). However, the placement of the jawphone as well as the frequency selection and other parameters of the device can affect the AEP testing results. 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 account for this in their protocol for known species. However, for untested species, this is an important factor to consider.

This project is using a computational approach to identify the mechanism(s) by which jawphones stimulate hearing when they are used to gather data on marine mammal auditory capabilities. The methodology is based on 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 complexity of specimens. Model outputs will quantify the acoustic pathways between the jawphone and the ear, which will enable researchers to develop sensitivity maps that identify the optimal locations for jawphone placement in three marine mammal species. These sensitivity maps can be used to design and evaluate AEP-based hearing tests, taking into account potential variable response sensitivity to the location of the transducer on the animal's skin. The maps can help to guide jawphone placement in order to achieve more accurate and consistent results.



Thus far, the project has generated preliminary 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 are still being evaluated but it does appear that the maps do vary between the species across the frequencies tested. The simulations performed for the bottlenose dolphin confirmed previous work that showed

the significance that the details of anatomic geometry can have for acoustic function.

Researchers are also evaluating potential differences in the conditions under which jawphones are used for AEP testing. The two primary conditions are in-air or in-water. Work still to be completed includes the final analyses of preliminary results and conducting an *in-situ* validation comparison.

> These results will help in both the design and evaluation of past and future AEP hearing tests.

These results will help in both the design and evaluation of past and future AEP hearing tests. They will enhance the ability to determine jawphone placement on stranded animals, and play an important role when measuring the hearing capabilities for new species yet to be 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 15-18

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

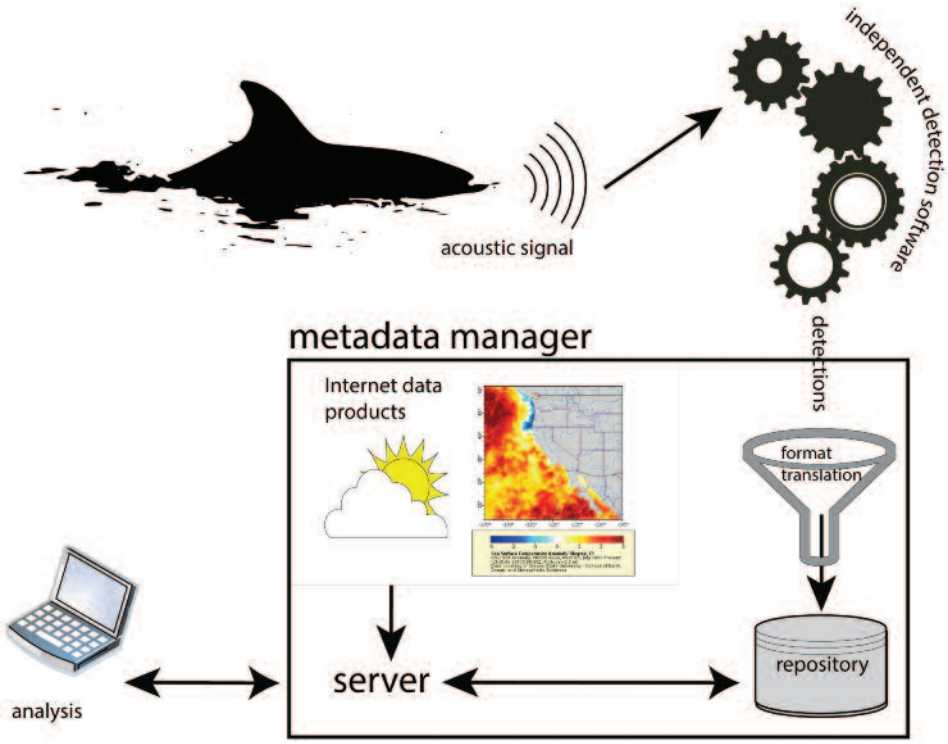
Current Navy-funded marine biological resource surveys span a variety of survey protocols and produce geo-referenced data products that are not necessarily consistent with one another, with developing inter-agency marine bio-data standards or with other established international standards for biogeographic data. An improved data management platform and a common set of metadata standards will help the Navy to meet monitoring requirements.

This project is expanding development of Tethys, a PAM metadata database sponsored by the 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.

> An improved data management platform and a common set of metadata standards will help the Navy to meet monitoring requirements.

Standardized data representations (schemata) have been developed in Tethys for describing instrumentation, effort, detections and localizations. This standardization within Tethys can be implemented on other systems and is becoming a community standard. It provides a solid foundation for developing an official one.

The project team is strengthening the capabilities of Tethys to make it more usable by the U.S. Navy. Specific tasks include providing additional data analysis and reporting facilities, identifying bottlenecks in perform-



Overview of workflow. Raw acoustic signals are processed by other software to produce metadata describing animal calls. The system can process output from a wide variety of formats. These metadata are stored in a data repository along with details about the instrument that recorded the calls. Scientists request data through interfaces available for several programming languages, and the interface provides access to other Internet available data products. (Sea surface height anomaly image courtesy NOAA Southwest Fisheries Science Center Environmental Research Division.)

ance as the existing databases continue to grow in size, and further developing the program's schemata for localization. These efforts will improve its utility for long-term Navy monitoring data management and support Navy mitigation efforts.

Significant progress was made on several tasks during 2016. The team added several data import enhancements, including the ability to import data from multiple sources. Performance bottlenecks were significantly improved during the year. One performance metric is the response time for queries producing more than 200,000 records; this was reduced by 60 percent with significantly higher gains for queries with millions of records. Steps toward enhancing localization schemata included working with Tyler Helble, from the Space and Naval Warfare Systems Command, to coordinate his localization data and to install Tethys for his group. A standards working group proposal was accepted by the Acoustical Society of America, enabling the work group to move forward on the standards process.

Work in the 2017 fiscal year will focus on several fronts. The team members will continue to develop tools for localization, working closely with Navy partners. The standards group will meet to discuss potential issues and solutions with moving the Tethys schemata towards an ANSI standard. They will begin to develop a web-based graphical user interface with the goal of providing non-program-based interfaces.

The project is a collaborative effort among the Navy, NOAA and the Bureau of Ocean and Energy Management (BOEM). It builds upon work previously funded by ONR.

About the Principal Investigator

Marie Roch is 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.

New Start

Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems

Principal Investigator: Aaron Thode
Project Status: New Start, Project 16-28

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

As part of the regulatory compliance process associated with multiple laws and regulations, the Navy conducts marine species monitoring to assess potential impacts from Fleet and SYSCOM military readiness activities involving active sonar and underwater detonations from explosives and explosive munitions.

A variety of PAM methods can be employed in monitoring efforts. These methods can include 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 (BSEE), are partnering in an effort to develop a standard for towed cabled PAM.

This project would help to support development of an Acoustical Society of America (ASA)-sponsored American National Standard ("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.

> Successful implementation of this standard for towed arrays would provide a template for other PAM technology standards.

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

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

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; and studying the relationship between visual censuses and acoustic call detection rate for gray whales.

INVESTMENT AREA 5: EDUCATION AND OUTREACH AND EMERGENT OPPORTUNITIES

Support education and outreach on LMR-funded research investments and new scientific methods available to the broader scientific community. Consider emergent research topics of priority interest to the Navy.

This investment area currently includes one ongoing project.

Ongoing

The Effects of Noise on Marine Mammals: Progress Since 1995

Principal Investigators:
Christine Erbe and Dorian Houser
Project Status: Ongoing, Project 14-10

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

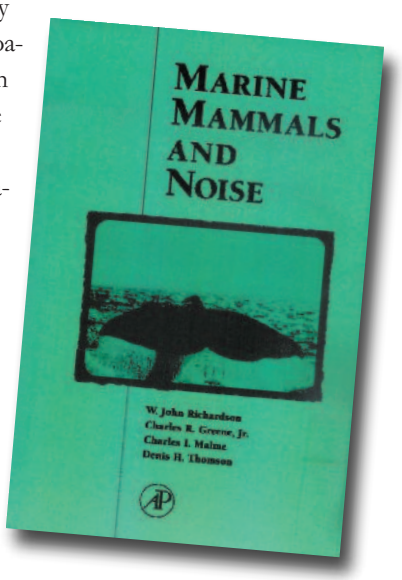
The book Marine Mammals and Noise (Richardson et al.) has been the single most cited resource for information on the effects of noise on marine mammals since its 1995 publication. It has been a valuable resource for the Navy, environmental planners, regulators and scientists. However, in the last 20 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 Navy environmental planners by consolidating two decades of marine mammal studies relevant to Navy environmental documentation and processes.

The LMR program is one of four stakeholders contributing funds to this important update. The other contributors are ONR's Marine Mammal Biology program, the National Oceanic and Atmospheric Administration and the Oil & Gas Joint Industry Programme.

Three tasks funded by the LMR program are:

1. Writing a critical review of the literature and publicly available data on the sounds produced by marine mammals and on marine mammal hearing
2. Developing a publicly accessible database of literature on marine mammal bioacoustics
3. Preparing a subsequent essay on how marine mammal bioacoustic data can inform both conservation efforts and the management of marine resources based on the literature review conducted.



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.

Project team members have drawn upon their own individual research databases, as well as identifying appropriate articles and reports from the scientific community and "grey" literature (reports that were not published in scientific journals) to develop a bibliographic database. Information includes data on sounds generated by marine mammals, including a review of the literature on production anatomy and physiology, and on the functional characteristics of marine mammal vocalizations. The database also reflects a review of the state of research on marine mammal acoustics including:

- Review of marine mammal biological classification
- Sound production by order
- Hearing (behavioral and electrophysiological)

- Noise effects (audibility, behavioral response, masking, effects on auditory physiology, effects on non-auditory physiology, chronic effects, biological significance, cumulative stressors, mitigation).

The research team has also completed the following for the summary and analysis of available information about the sounds produced by marine mammals:

- Literature review on sound production
- Tabular summary of acoustic characteristics by taxon
- A taxonomic breakdown
- Summary of regional differences
- Spectrogram collections of the best documented and illustrative vocalizations
- Overall critical summary of source levels, call structure and regional differences.

As of late 2016, the team had added 5,144 references to the database. The book, organized into ten chapters, is expected to be approximately 700 pages. At the close of the project in 2017 the team will submit the manuscript for publication and make the database publicly available online.

Project results will support Navy environmental planners by consolidating two decades of marine mammal studies relevant to Navy environmental documentation and processes. The project's final essay will provide Navy-specific recommendations.

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 bio-acoustic 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

Working with other organizations on related projects helps the LMR program to leverage funding, expand investigation options and draw on additional expertise. Of the five partnership projects now underway, three are ongoing and two are new starts.

Ongoing

Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales

This project is a collaboration between the LMR program and the Environmental Security Technology Certification Program (ESTCP). 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 (Slocum gliders, wave gliders and moored buoys)
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.

Successful demonstration and validation of this technology will improve efficiency of existing monitoring technologies by including near real-time detection information on marine species occurrence.

The combined hardware/software system used is a digital acoustic monitoring instrument (DMON) and low-frequency detection and classification system (LFDCS). This system is deployed on the three autonomous platforms. The platforms were first deployed in the Atlantic, off the New England coast, in 2015 and again in 2016. The autonomous platform deployments were supplemented by co-located visual monitoring from ships, aerial surveys and land-based observation platforms to provide data on the visual and acoustic detection rates for the four endangered species. The purpose of this was to validate the near real-time detector and classifier performance on the three autonomous platforms, in comparison with archival audio and visual survey data.

One autonomous platform tested by the project includes a hydrophone array within the black tube at the base of the platform.
Mark Baumgartner

A spring 2016 deployment in the Great South Channel included a Naval Oceanographic Office (NAVO) Slocum glider. This successful one-month deployment demonstrated the use of the DMON/LFDCS package on a Navy asset and is a first step at transitioning the system to the Navy Marine Species Monitoring program. 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. The moored buoy platform that was scheduled to deploy in late 2015 suffered electrical issues, vandalism and noise, resulting in redeployment and mooring redesign in 2016. The wave glider platform also 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 into 2017.

> This successful one-month deployment demonstrated the use of the DMON/LFDCS package on a Navy asset and is a first step at transitioning the system to the Navy Marine Species Monitoring program.

All three 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 will greatly improve the accessibility of the data and provide a useful tool to augment visual survey data in areas of Navy interest.

Principal Investigators

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Northeast Fisheries Science Center

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

The OPNAV N45-funded project "Survey Software Toolkit for Data Collection, Data Workflow and Data Delivery" is streamlining survey data collection so that all aspects of the workflow become more efficient. The data collection toolkit field application will be structured for easy synchronization or export of data displays including maps, tracklines, sighting data and many other items. A web management component of the proposed system provides an efficient interface to view and analyze collected data. The ability to quickly review survey data from any internet connected computer, including visualizing spatial components on high-performance web maps, will increase opportunities for collaboration among members of the Navy marine species monitoring community regardless of geographic location. The end result will offer marine species monitoring data that have undergone thorough quality control, are standardized and provide critical information to support Navy planning.

By the close of 2016, the base surveys (aerial, vessel and shore) have been completed, as has the initial web application. Additional programming and customization are ongoing along with field trials and testing. Document preparation and development are underway in anticipation of demonstrating and validating the software.

The Navy Marine Species Monitoring program has provided the primary Navy guidance during development and testing of the toolkit to ensure that it meets the Navy's needs.

Principal Investigator

Michael Richlen
HDR Environmental Inc.

Sonobuoy Liaison Working Group

The Sonobuoy Liaison Working Group (SLWG) continues to play an important role in supporting sonobuoy allocations to marine mammal research and monitoring.

The SLWG includes representatives from a large variety of Navy branches and helps to determine how many sonobuoys are made available to the Navy's Non-Combat Expenditure Allocation (NCEA). The Navy's NCEA of sonobuoys includes a quantity of non-expired sonobuoys that can be made available to researchers. Sonobuoys, most often used by the Navy for submarine detection, have proven to be a valuable asset in understanding and locating marine mammals.

LMR works to match available sonobuoys with priority research projects. Beginning in FY16, LMR implemented a more formalized process for researchers to request sonobuoys. Researchers completed a Sonobuoy Request Form by February 1; LMR then reviewed the requests, made decisions on which projects would receive sonobuoys, and submitted a final list to the SLWG by March 3 to handle distribution.

All 480 sonobuoys were allocated. Projects receiving sonobuoys during 2016 are identified in the following table.

New Starts

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

To meet regulatory requirements, the Navy needs information about how protected marine species respond to sound exposures. Ongoing behavioral responses studies entail at-sea, boat-based visual detection, tagging and tracking of animals in coordination with simulated sound sources and Navy ships. An alternative, and complementary, method to this logistically difficult approach potentially could use PAM data.

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 ranges. Such methods could support more efficient studies of marine mammal response to sound on Navy at-sea ranges.

PROJECT	ORGANIZATION
California Cooperative Oceanic Fisheries Investigations (CalCOFI) Surveys	University of California at San Diego/ Scripps Institution of Oceanography
North Pacific Right Whale Surveys	National Marine Mammal Laboratory/ Alaska Fisheries Science Center
Southern Resident Killer Whale & Ecosystem Surveys	Northwest Fisheries Science Center
Atlantic Marine Assessment Program for Protected Species (AMAPPS) cruise	Southeast Fisheries Science Center
Mysticetes in the Northeast/AMAPPS cruise	Northeast Fisheries Science Center
Main Hawaiian Islands Survey	Pacific Islands Fisheries Science Center

This effort is a partnership among ONR, LMR and PACFLT. It will support developing the 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 the ongoing reporting required by PACFLT.

Within the LMR portion of this effort, the project team will develop three software tools to help analyze metrics needed for the ONR BREVE effort and PACFLT monitoring efforts:

- An interface for acoustic modeling software to automatically estimate sonar sound pressure levels (SPL) and sound exposure levels (SEL) to tracked animals. The interface will be designed for available Navy standard models in order to automate the SPL/SEL estimation process. The team will also use "Peregrine," a C-code version of the Range Dependent Acoustic Model (RAM) developed by OASIS.
- Automated track kinematics software to group whale localizations into tracks and to automatically extract relevant swim kinematics (e.g., animal's speed, direction, depth, etc.). The methods developed within this tool will allow for automatic implementation of metrics developed under the BREVE project. This will allow for bulk processing of tracks to reduce the need for human operator involvement.
- Automated classifier for track information to process the thousands of tracks contained in archived data sets, in addition to new data. This will integrate available classifiers, with modifications as needed to work on the PMRF and the Southern California Offshore ranges.

These three tools will support efficient marine mammal reporting on Navy instrumented ranges, particularly if information beyond species-specific presence/absence is to be reported. These automated tools ultimately will facilitate work for PACFLT monitoring.

Principal Investigators

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Elizabeth Henderson
Space and Naval Warfare Systems Command

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

In recent years, substantial advancements have been made in using statistical classifiers to identify odontocete species based on the properties of their whistles and clicks. Most species classifiers have been developed using passive acoustic data collected at the sea surface. It currently is unknown if these classifiers will be suitable for analyzing data obtained by seafloor recorders at depth because the depth of the animals and receivers, distance of animals from the receiver and sound propagation may all influence properties of received whistles and clicks and therefore impact classification results.

This project, a partnership of ONR, LMR and U.S. Fleet Forces Command, is examining how species-specific signaling cues received at recorders at different depths are affected by these factors. The project team is using both surface-deployed and bottom-moored vertical arrays of hydrophones and autonomous recorders to obtain recordings at different depths in the water column from a variety of free-ranging odontocete species and Navy-trained captive dolphins stationed at a known depth.

Field work was completed in 2016 and analysis is ongoing. The results of this effort will ultimately provide a better understanding of the methods currently used to monitor marine mammals in Naval training areas and will increase confidence in their application.

Principal Investigators

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Oceanwide Science Institute

Julie Oswald
University of St Andrews in Scotland

LOOKING AHEAD

Humpback whale.

LOOKING AHEAD

In 2017 we look forward to seeing several publications, results and methods from LMR-funded research transition into application within the Navy's environmental compliance process. Several LMR projects will be completed in 2017 and will be available for transition or further investigation.

One transition highlight during 2017 will be the SOCAL-BRS. Along with over 20 publications on the scientific findings, the basic tools and methods developed from this LMR- and ONR-sponsored project will be applied in the Atlantic to collect marine species behavioral response data in conjunction with Navy training events off of Cape Hatteras. In addition, the detailed baseline data on movement and acoustic behavior of cetacean species and the individual high-resolution measurements of behavioral changes during exposure will be critical for the Navy's acoustic effects analysis. The project's tools and methods (e.g., tagging, focal follows) will be transferred to the Navy's monitoring programs to expand data collection capabilities. The results forthcoming from the BRS efforts demonstrate the success of ONR and LMR's investments, and broaden our capability to collect these data that are so important to the Navy's refinement of the risk threshold criteria.

The priority research needs that were defined during 2016 will focus our efforts for 2017 and beyond. New projects will be selected from proposals received in response to the FY17 Broad Agency Announcement on the following three topics:

TOPIC 1: Measuring Explosive Effects to Marine Mammals

TOPIC 2: Understanding the Range to Effect to the Behavioral Response of Marine Mammals from Sonar Exposure

TOPIC 3: Coordination for the Advancement of Density Spatial Modeling Methods Using Visual and Acoustic Survey Data

These projects will expand the amount of scientific data needed to refine the risk threshold criteria. The published results from the studies initiated in FY17 could be available during the analysis of the next compliance cycle.

Looking beyond 2017, continued Navy investment in tools, technologies and methods will enable us to collect marine species data and to investigate critical questions about the effects of Navy training and testing activities. Because the oceanic environment is a difficult place to study and many of the tools and technologies are not readily available, clear answers don't always appear as quickly as desired. Nevertheless, continued efforts to advance methods and technologies, such as the next generation DTAG, and advancing opportunistic methods of study, can provide us valuable behavioral response data. The results from such work will be necessary to sustain at-sea training and testing.

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 enable us to invest in priority research topics. In addition, the LMR program will continue to work closely 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, while preserving core Navy readiness capabilities.

LMR Publications

Included here is a list of publications from 2016 that were partially or fully funded by the LMR program. These publications are of great value to the Navy's at-sea environmental compliance process and directly feed into NEPA, MMPA and ESA compliance documentation.

For a list of publications from prior years, see the previous LMR program reports at greenfleet.dodlive.mil/LMRYIR.

Allen, A.N., Goldbogen, J.A. Friedlaender, A.S., Calambokidis, J. In press. An automated lunge detector for surface and deep feeding fin whales. *Methods in Ecology and Evolution.*

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Finneran, J.J., Mulsow, J., Houser, D.S., and Burkard, R.F. (2016). Place specificity of the click-evoked auditory brainstem response in the bottlenose dolphin (*Tursiops truncatus*), *Journal of the Acoustical Society of America,* 140(4): 2593-2602.

Friedlaender, A.S., Hazen, E.L., Goldbogen, J.A., Stimpert, A.K., Calambokidis, J. and Southall, B.L. (2016). Prey-mediated behavioral responses of feeding blue whales in controlled sound exposure experiments. *Ecological Applications*. doi:10.1002/15-0783.

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Premus, V., Abbot, P., Gedney, C., Christman, R., Helfrick, M., Campbell, R., and Douglas, K. (2016). IRAP: An integrated, real-time, autonomous passive acoustic monitoring system for beaked whale detection, localization, and tracking. *Journal of the Acoustical Society of America,* 140(4): 3181.

Roch, M.A., Batchelor, H., Baumann-Pickering, S., Berchock, C.L., Cholewiak, D., Fujioka, E., Garland , E.C., Herbert, S., Hildebrand, J.A., Oleson, E.M. et al. (2016). Management of acoustic metadata for bioacoustics. *Ecological Informatics* 31: 122-136, doi.org/10.1016/j.ecoinf.2015.12.002.

Southall, B., Calambokidis, J., Moretti, D., Stimpert, A. Douglas, A., Barlow, J., Keating, J., Rankin, S., Southall, K., Friedlaender, A., Hazen, E., Goldbogen, J., Gailey, G., Allen, A. (2016). Project report: Biological and Behavioral Response Studies of Marine Mammals in Southern California, 2015 (SOCAL-15).

Southall, B. L., Nowacek, D.P., Miller, P.J.O., and Tyack, P.L.T. (2016). Synthesis of Experimental Behavioral Response Studies Using Human Sonar and Marine Mammals. Endangered Species Research, 31: 291-313. doi: 10.3354/esr00764

Wiggins, S.M. and Hildebrand, J.A. (2016). Final Report Living Marine Resources: ID-33 Technology Demonstration for Fleet Passive Acoustic Monitoring. MPL Technical Memorandum 608.

Acronyms

ABR . . . . . Auditory brainstem response
AEP . . . . . Auditory evoked potentials
ASA . . . . . Acoustical Society of America
AUTEC . . . . . The Atlantic Undersea Test and Evaluation Center
AUV . . . . . Autonomous Undersea Vehicles
BAA . . . . . Broad Agency Announcement
BOEM . . . . . Bureau of Ocean Energy Management
BREVE . . . . . Behavioral Response Evaluations Employing Robust Baselines and Actual Navy Training
BRS . . . . . Behavioral Response Study
DCLT . . . . . Detection, classification, localization and tracking
DET . . . . . Detection error trade-off
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
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
MF . . . . . Mid frequency
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
NEPA . . . . . National Environmental Policy Act
NMFS . . . . . National Marine Fisheries Service
NMMF . . . . . National Marine Mammal Foundation
NOAA . . . . . National Oceanic and Atmospheric Administration
ONR . . . . . Office of Naval Research
OPNAV N45 . . . . . Chief of Naval Operations Energy and Environmental Readiness Division
PAM . . . . . Passive acoustic monitoring
PMRF . . . . . Pacific Missile Range Facility
PTS . . . . . Permanent Threshold Shift
RDT&E . . . . . Research, development, test and evaluation
ROC . . . . . Receiver-operator curves
ROCCA . . . . . Real-time Odontocete Call Classification Algorithm
SCORE . . . . . Southern California Offshore Range
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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