
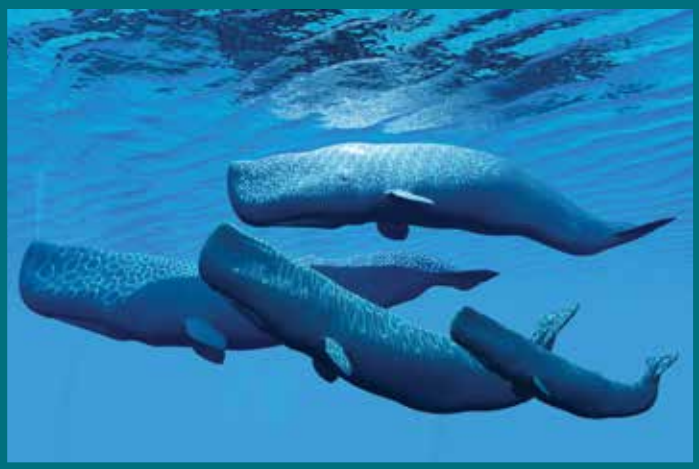




The Living Marine Resources Program Report 2015

SCIENCE • STEWARDSHIP • NAVY READINESS

livingmarine RESOURCES

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Please 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.

A Word from the Program Manager

Welcome to the second annual report for the Navy's Living Marine Resources (LMR) program. I hope this report provides you with some insights into where we've been, where we're going, and how the research sponsored by the LMR program supports the Navy's at-sea environmental compliance process. Fiscal Year 2015 (FY15) was an exciting year during which we began to see the positive effects from the changes made in the management of the program.

Among our other accomplishments during FY15, we launched the following eight new projects:

1. Standardization of Auditory Evoked Potential (AEP) Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database (Dorian Houser)

2. Behavioral Audiometry in Multiple Killer Whales (Brian Branstetter)

3. Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments (Ted Cranford)

4. Passive Acoustic Density Estimation of Baleen Whales: Using Sonobuoys to Estimate Call-Rate Correction Factors (Shannon Rankin)

5. Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data (Ana Širović)

6. Acoustic Metadata Management for Navy Fleet Operations (Marie Roch)

7. DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed sensors in Testing and Evaluation Areas (Len Thomas)

8. Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises (Ron Kastelein)

These new projects reflect efforts to diversify the program's portfolio of projects to ensure that we meet the Navy's expanding research needs.

Our ongoing projects completed another year of research. There have been many positive changes in each project in response to the feedback both from the LMR Advisory Committee (LMRAC) at the annual In-progress review and from the program management team. This type of feedback and response is incredibly valuable to a 6.4 Research, Development, Test and Evaluation program that is focused on addressing specific Navy research needs identified by the Fleets and System Commands.

More insights into all of the LMR projects are provided in Section 2 of this report, "Program Portfolio," and on our web site at www.lmr.navy.mil.

Other efforts during FY15 included continuing to improve how the LMR program functions. We streamlined and refined contracting procedures, kickoff planning, and program expenditure monitoring. In addition, all documents regarding the Broad Agency Announcement submission process were revamped to provide additional guidance and instructions. The changes were welcomed based on the numerous positive comments we received about our clear proposal submission process. We always welcome feedback on improving the guidance on the process.

We also restructured our program budget schedule to increase the probability that we will continue to meet obligation and expenditure benchmarks and make room for more "new start" projects. These efforts helped us to meet our year-end benchmarks for the first time since the transition of the program to the Naval Facilities Engineering and Expeditionary Warfare Center.

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Overall, I am glad to report the many ways by which the LMR program continues to benefit the Navy, including:

- Funding applied research directly supporting Navy needs driven by the compliance process.
- Providing a vehicle (the LMRAC) to facilitate coordination among the Navy Marine Species Monitoring program, Office of Naval Research's Marine Mammal and Biological Oceanography Program, and the LMR program.
- Anticipating needs in the Navy's acoustic effects analysis for next compliance cycle (per National Environmental Protection Act, Marine Mammal Protection Act, Endangered Species Act).
- Reducing the need for the Navy's marine species monitoring program to "lean forward" and take on risky investments with limited funds.
- Providing a pathway for clear communication between the Navy and scientists on the Navy's priority research needs and on opportunities to improve the quality and value of Navy-funded research efforts.

I want to thank our resource sponsor, Chief of Naval Operations Energy and Environmental Readiness Division and all the members of our management team, including the LMRAC, for all of their efforts to sustain the LMR program over the past three and a half years. Their involvement and support were invaluable during the review of the many proposals we received during this past year. They also were critical participants in our efforts to oversee the ongoing research of the program during our annual review and elsewhere. The program continues to be transparent and relevant to the Navy mission because they are involved.

Anu Kumar
Program Manager

PROGRAM OVERVIEW

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 U.S. 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 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 establishing the new program. This included setting up a program office, defining Standard Operating Procedures (SOP), 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.

Since Dr. Gisiner's retirement in June 2014, Anu Kumar has managed the LMR program.

***Acronyms used in the report are listed on page 48.**

Responsibility and Coordination of Navy's Research and Monitoring Programs

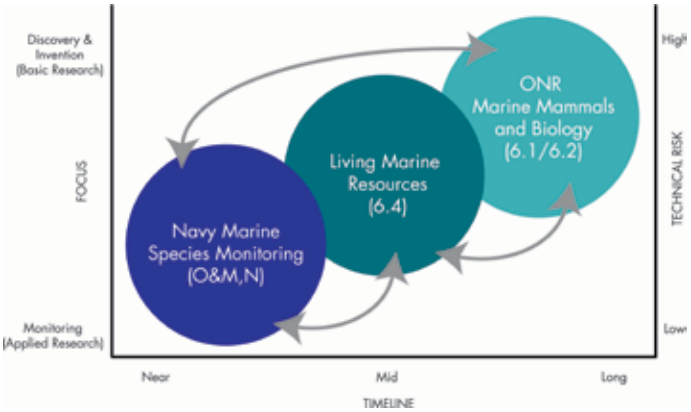
Multiple Navy organizations are involved in developing and implementing the means to meet federal permitting requirements for Navy at-sea training and testing activities. To ensure coordinated and efficient efforts, the Navy worked with regulatory agencies, marine experts and Navy personnel to develop 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 programs:

1. The Office of Naval Research (ONR) Marine Mammals and Biology program

2. The LMR program

3. The U.S. Navy Marine Species Monitoring program

Pilot whale. Adam Li; NOAA/NMFS/SWFSC.



The Office of Naval Research Marine Mammals and Biology Program

The Office of Naval Research's Marine Mammals and Biology (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.

For more information about the ONR MMB program go to: www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology.aspx.

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 and monitor living marine resources. The LMR program is structured to be customer focused and to address the needs of the Navy's environmental community. This is accomplished by the program having an advisory committee with representation consisting of Navy end users and other program managers (ONR and the Marine Species Monitoring program). ONR projects may be selected for continued development, demonstration and validation when the project is deemed ready to transition to the next stage of development. 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.

For technological solutions, the LMR program is unique because it 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.

U.S. Navy Marine Species Monitoring Program

As part of the regulatory compliance process associated with the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (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 Navy's Marine Species Monitoring program is a direct outcome of MMPA Letters of Authorization issued to the Fleets and SYSCOM activities. (For more information about the Navy's marine species monitoring efforts go to: www.navymarinespeciesmonitoring.us)

The U.S. Navy Marine Species Monitoring program typically uses tools that have already been developed under the ONR 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 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.

Humpback whale. Elliott Hazen; NMFS/SWFSC/ERD; NOAA permit 14245.

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 issues as well as members of the Navy's research and implementation community. The LMRAC includes representatives from OPNAV N45, Office of the Assistant Secretary of the Navy for Energy, Installations and Environment, Commander Pacific Fleet, U.S. Fleet Forces, Space and Naval Warfare Systems Command (SPAWAR), Naval Sea Systems Command (NAVSEA), Naval Air Systems Command (NAVAIR), ONR, and Chief of Naval Operations for Information Dominance (N2/N6).

Technical Review Committee

The TRC consists of scientific subject matter experts from within the Navy, other federal agencies, industry or academia, as appropriate. Committee membership changes from year to year to ensure that the areas of expertise needed to review submitted proposals are provided.

Program Office

The LMR program is managed by NAVFAC EXWC in Port Hueneme, CA. The LMR program manager assumes the overall responsibility for the execution of 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. 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. Projects in this area can include new detection and

classification algorithms and automated processing tools for passive acoustic monitoring data.

3. *Monitoring and mitigation technology demonstrations.* Demonstrate technologies that offer to enhance marine species monitoring capabilities. Projects in this area can include new passive acoustic monitoring 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. 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 to make results available to the broader scientific community. Consider emergent research topics of priority interest to the Navy. Projects in the area can include the LMR web site and program outreach on investments, 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 environmental needs that meet one or more of the following conditions:

- Addresses research challenges being faced by the Navy community
- Identifies an existing gap in knowledge, technology and/or capability
- Is associated with an environmental constraint or regulatory driver.

Anyone within the Navy may submit needs for consideration by the LMR program (a guide for submitting needs is available at www.lmr.navy.mil under "Needs"). Submitted needs are validated and ranked by the LMRAC, and then recommendations are made to the OPNAV N45 resource sponsor.

Approved needs 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 section 2 of the report, "Program Portfolio."

- 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

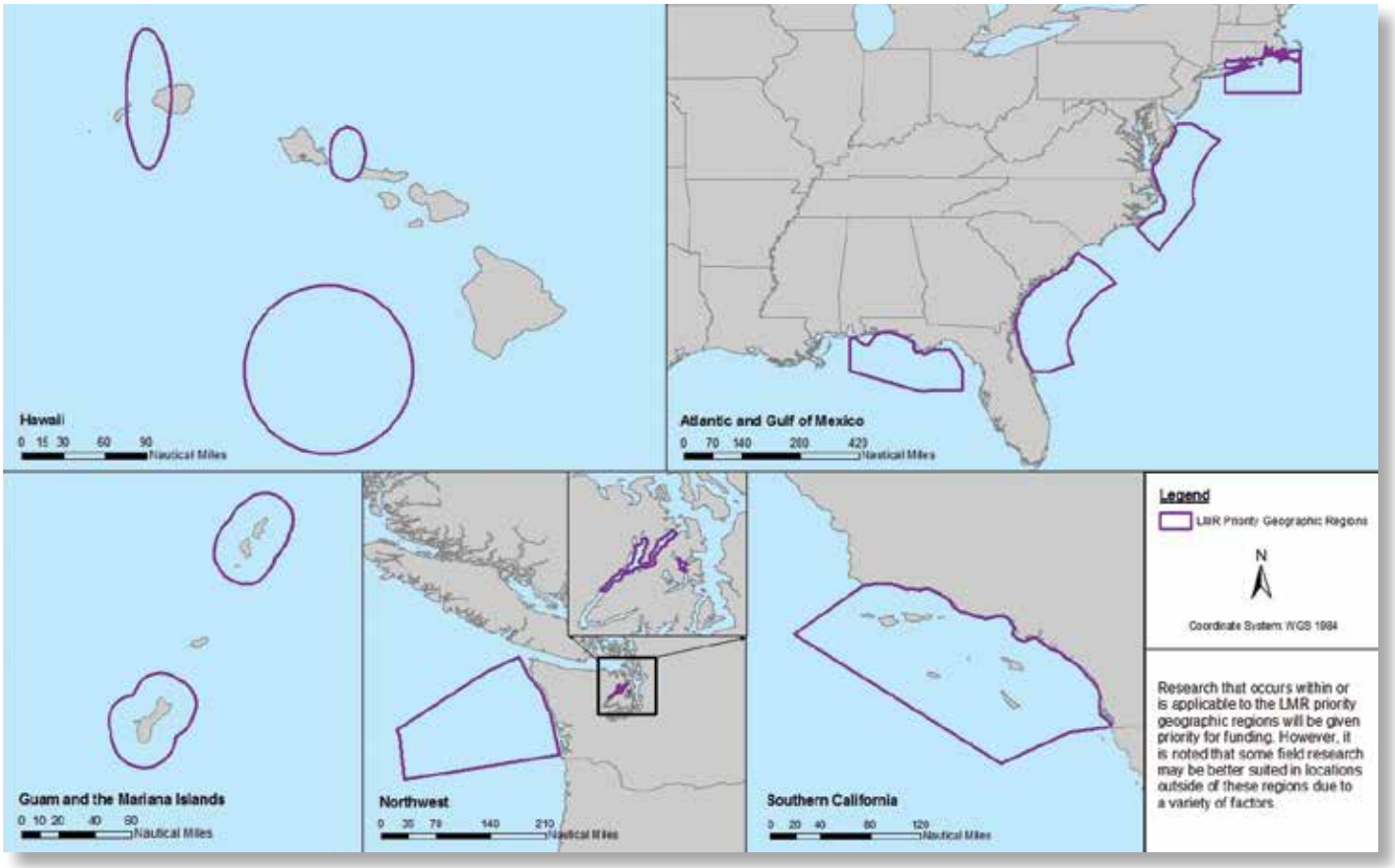
Priority Species and Geographic Regions

In addition to the program investment areas and the identified needs, the program also considers priority species and geographic regions when evaluating and ranking proposals for program funding. While the program is interested in increasing knowledge and understanding of all marine mammal species, projects must be considered within program budget. In order to provide some guidance on research priorities, the priority marine mammal species for the program include:

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

In addition to marine mammal species, the LMR program also is interested in increasing knowledge and understanding of the potential impacts to sea turtles, diving sea birds, and fish when specifically 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 maps below show the LMR program's priority geographic areas. It is important to note that the LMR program acknowledges that some field research may be better suited outside of these geographic regions due to a variety of factors.



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 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 can 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 does continue to track a project's success and solicit feedback about the integration. Some of the conditions that define successful integration include:

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

Management and Communication Tools

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

LMR Web Site

The program web site (www.lmr.navy.mil) serves as a centralized repository for information pertaining to program management and project execution. The site provides the latest information about critical deadlines, project successes and other information essential to key program personnel across the Navy. The web site also allows personnel from other R&D programs to obtain up-to-date insights into the LMR program's priorities and ongoing projects.

The web site also is a key tool supporting the program's annual process of soliciting Navy needs, soliciting pre-proposals and proposals and tracking project progress. As previously noted, Navy needs are submitted via the web site. Researchers responding to the annual BAA must submit their pre-proposals through the web site. Full proposals, management plans for funded projects and subsequent quarterly status reports all are submitted to and maintained on the site. These functions support sound program investment decisions.

In addition to the password-protected management portion, the site also includes a public section that includes links to program details, defined environmental needs, pre-proposal dates and processes, project highlights, and our newsletter, *LMR News*. The home page also lists program happenings.

Quarterly Newsletters

The LMR program issues a quarterly newsletter, *LMR News*, to provide readers with the latest information about program operations, significant accomplishments, milestones, and future investment areas for the LMR program. The digital newsletter can be found at the LMR web site. 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, available on the LMR web site, provide a summary of the following for each project:

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


Behavioral Dose-Response Relationship and TTS in Harbor Porpoises


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

In-progress Review

Each Principal Investigator is required to provide a technical briefing to the LMRAC and invited TRC subject matter experts at the program's annual In-Progress Review (IPR). IPRs are typically held in the fall, after most field season efforts have concluded. The objectives of these IPRs are to review project progress, technical issues and accomplishments, integration issues and accomplishments, and to determine if any corrective actions are needed. A template for preparing an IPR presentation is provided on the LMR web site.

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 the status of 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.

PROGRAM PORTFOLIO: FUNDED PROJECTS AND PARTNERSHIPS

Funded Projects by Investment Area

As summarized in the preceding section, the program has defined five investment areas within which projects are funded. This section provides an overview of ongoing projects (initiated prior to FY15) and briefly introduces new projects funded during FY15 ("new starts"). The project summaries are grouped within their investment area.

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.

Addressing the risk threshold criteria requires multi-faceted understanding of marine mammals present in Navy training areas. Questions include what species are present, how many, what are they doing, how and what do they hear, to what sounds do they respond and how do they respond? Multiple techniques are employed to collect and analyze the data needed to address these questions. Techniques include passive acoustic monitoring, visual surveys, biological sampling, tracking tags and direct study and research.

Each of the projects in this investment area is helping to address one or more of these questions. Four of the projects are ongoing and three are new starts. The projects summarized below are:

- Marine Mammal Monitoring on Ranges (M3R)
- Southern California Behavioral Response Study (SOCAL BRS)
- Electrophysiological Correlates of Subjective Loudness in Marine Mammals
- Primary Audiograms of Hearing in Baleen Whales
- Behavioral Audiometry in Multiple Killer Whales
- Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments
- Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises.

Ongoing

Marine Mammal Monitoring on Ranges (M3R)

Project number: 01
Need addressed: N-0011-13 Behavioral Responses Of Marine Mammals To Navy Sound Sources
Co-Principal Investigators: Dave Moretti, Project Manager (Naval Undersea Warfare Center); Diane Claridge, AUTEC research team (Bahamas Marine Mammal Research Organization); John Durban, AUTEC research team (National Oceanographic and Atmospheric Administration); Erin Falcone, SCORE research team (Cascadia Research Collective); Greg Schorr, SCORE research team (Cascadia Research Collective); Robin Baird, PMRF research team (Cascadia Research Collective); and Daniel Webster, PMRF research team (Cascadia Research Collective)

The Marine Mammal Monitoring on Ranges (M3R) program is a multi-year, collaborative effort that utilizes existing hydrophone (underwater microphone) arrays on Navy ranges to expand our knowledge about marine mammal presence, abundance and behavior using passive acoustic monitoring, visual observation, biological sampling, and satellite tags. 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.). These sounds are detected on individual hydrophones as an animal, or group of animals, vocalizes within the range.

The goals of the M3R program are 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 the 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.

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.

Ultimately, to significantly improve Navy monitoring capabilities, the Navy will need approaches to passive acoustic monitoring that do not require marine mammal experts to collect the data. The focus of the transition of M3R was to develop a system that could be run by existing Navy range personnel to collect data prior to, during, and after training and testing exercises. Implementing these tools on existing fields of hydrophones on Navy ranges allows us to leverage and enhance existing methods available to the Navy.

The M3R program has developed a digital signal processor (DSP) architecture that incorporates hardware and software to capture and process marine mammal sounds, classify some 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.

To verify the passive acoustics data, on-water sighting data are being collected to provide a direct observation of species identification, physical behavior, group size, and population demographics along with biopsy sampling and prey mapping. These data provide insight into population dynamics and prey utilization on the ranges. Biopsy samples are used for a project, funded by the Office of Naval Research (ONR), that is studying hormone analysis as possible stress indicators and fatty acid analysis to gain insight into prey utilization. During focused field efforts throughout the year, satellite tags are also being 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 are evaluated along with precise ship tracks and sonar received level measurements, to investigate the effects of repeated sonar exposure on cetaceans. The focus of this study is on deep diving Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales, which have been the predominant species present in stranding incidents related to sonar. The real-time passive acoustic monitoring capability of M3R has proved to be a significant aid to the tagging field team to find these cryptic species.

A breaching juvenile Blainville's beaked whale. This individual breached repeatedly on PMRF near a Navy monitoring vessel in 2012. Mark Deakos; NMFS permit #14451.

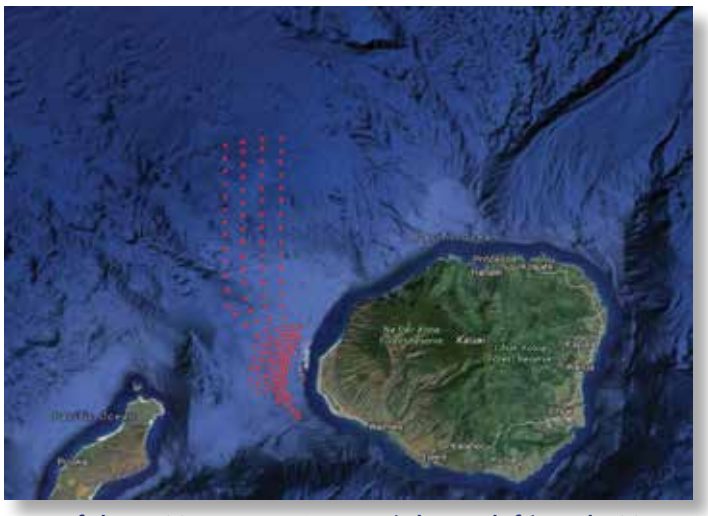
The M3R program is currently being developed and integrated at three Navy undersea ranges equipped with arrays of broadly spaced (1-4 miles), bottom-mounted hydrophones:

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.

The Office of Naval Research initiated M3R in 2000 to investigate the possibility of leveraging existing Navy range hydrophones to monitor cetaceans. The program documented the presence of Blainville's beaked whales on a Navy range where MFAS was routinely used. Initial monitoring algorithms were developed and implemented on the Versa Module Europa (VME)-based range DSP. A stand-alone Linux cluster-base architecture was designed and implemented. 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.



Two of three M3R sites–AUTEC (above, left) and PMRF (above). The red areas show the hydrophone arrays.

In 2009, the core M3R program development was transitioned from ONR to LMR and prototype technologies were extended and used to study animals on the ranges. M3R is transitioning its monitoring and analysis tools so that they might be run and maintained by Navy range personnel. During FY15 the project 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.

Currently, the core capability and operation of M3R is being transitioned to the Navy Marine Species Monitoring program. This will allow for continuous monitoring of animals on the ranges and will provide ongoing data to evaluate changes in beaked whale abundance, density and distribution on the ranges based on acoustic detections.

In addition, M3R data collected under the LMR program are being used to develop improved behavioral risk criteria, the results of which will be applied to the Navy's acoustic impact analysis for Phase III environmental compliance. ONR investments play a vital role

in analyzing M3R observations as integrated models of animal response to sound and further studying the possible biological significance of those responses.

As the core function of the M3R technology is transitioned, the breadth of data available on marine mammals will substantially increase. This will assist in providing insight on understanding baseline cetacean behavior and the potential effects from training and testing. This will provide real-time marine mammal monitoring capabilities in support of range operations.

Because the M3R system and range tracking systems employ identical system architectures, the transition will contribute to maintaining an overall integrated system software repository. It will help to ensure 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 the Navy and, through collaboration with the PI, can be further developed by outside scientists.

The Southern California Behavioral Response Study

Project number: 02
Need addressed: N-0011-13 Behavioral Responses of Marine Mammals to Navy Sound Sources
Co-Principal Investigators: Brandon Southall, Chief Scientist (SEA, Inc.); John Calamokidis, Project Manager (Cascadia Research Collective); 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)

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 mid-frequency active sonar (MFAS) on marine mammal behavior.

The project began in 2010 and completed its most recent field season in 2015. The overarching approach has included a number of research objectives:

1. Tag a variety of species and obtain baseline behavioral data

2. Conduct controlled exposure experiments (CEEs) to obtain high-resolution measurements of behavioral responses of marine mammals

3. Apply adaptive team configuration to support both simulated MFAS sources and actual military MFAS sources

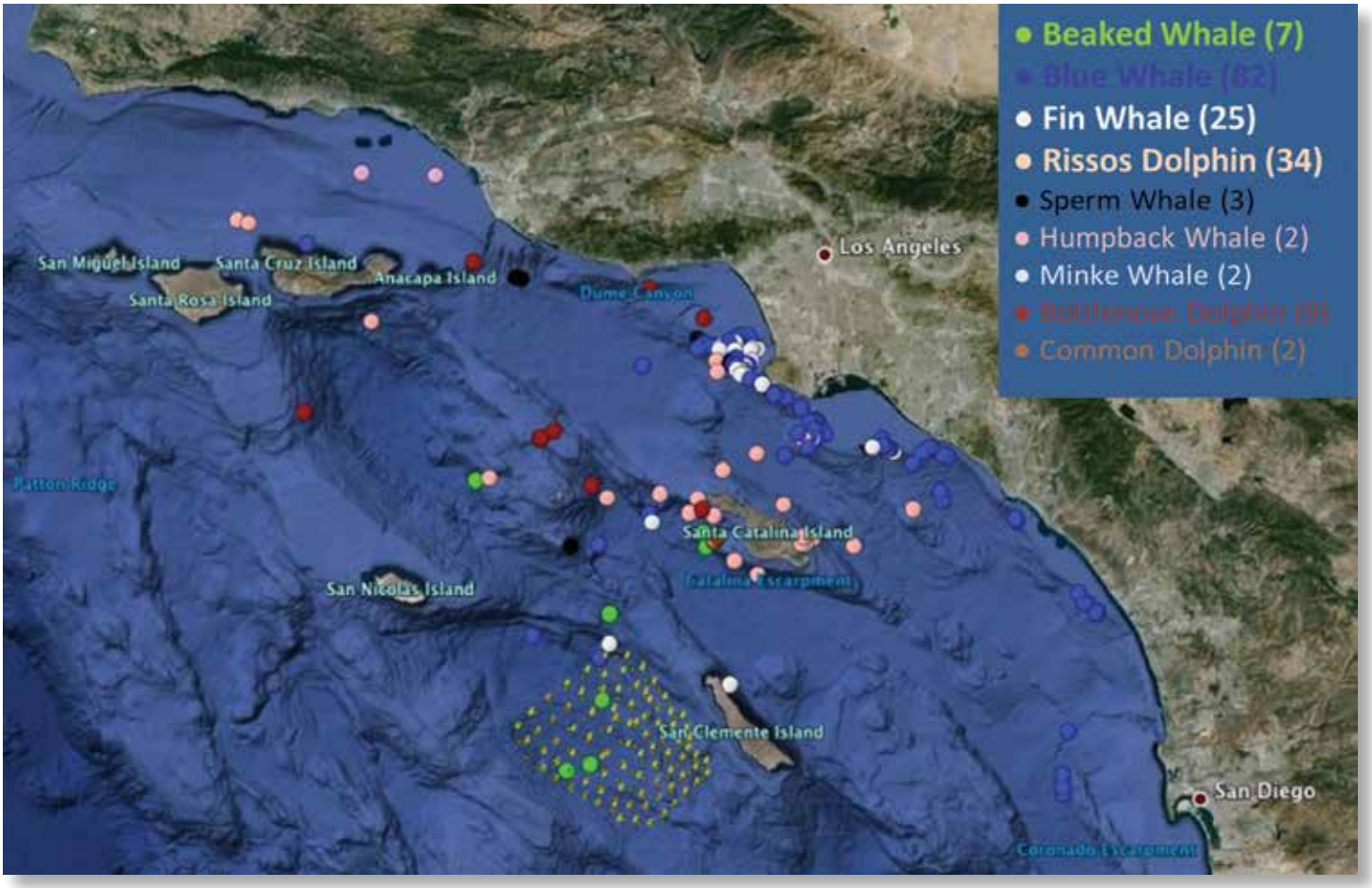
4. Obtain basic biological, behavioral, and foraging ecology data for marine mammals to support range monitoring efforts and/or habitat models.

The teams conducting fieldwork to measure baseline behavioral data and conducting CEEs include members with wide ranging expertise in applying a variety of monitoring and analytical tools. These include visual observers, tagging teams, sound source engineers and fisheries acoustics biologists who conduct photo identification, passive acoustic monitoring, geographical information system (GIS) tool application, acoustic modeling, and advanced bio-statistical analysis.

Prior to CEEs, tags are deployed on focal animals, underwater acoustical monitoring (towed passive acoustic monitoring and fixed range hydrophones when available) is utilized, and visual observers monitor focal and other animals and determine if particularly vulnerable animals (e.g., neonate calves) are present. Controlled exposure experiments involve a simulated sound source, producing pseudo-random sounds and simulated MFAS, as well as actual MFAS sources. All work is conducted within the terms of applicable federal and state permits and efforts are made to transparently communicate methods and results in scientific meetings and to the public.

As new data are collected and analyzed, the teams refine methodologies 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. SOCAL BRS is providing the Navy with baseline data on movement and acoustic behavior of a variety 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 160 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. Measurements are providing quantitative insights into the critical importance of exposure context (e.g., distance from source, depth, behavioral state at time of exposure, etc.) in terms of the probability and type of behavioral response.

Sixteen peer-reviewed publications of baseline and CEE results to date have been produced by SOCAL BRS (a dozen more are currently in review or advanced stages of publication), the results of which are being applied to the Navy's behavioral response assessment for Phase III environmental compliance. Four publications for this project came out in 2015. Please see the LMR Program References section at the end of this report for additional details.



SOCAL BRS Tagging Locations from 2010-2015. The instrumented range is shown as yellow dots next to San Clemente Island.

The guided-missile destroyer USS William P. Lawrence (DDG 110) transits toward San Diego Harbor. U.S. Navy photo by Mass Communication Specialist 3rd Class Nathan Burke.

SOCAL-15 field work was conducted between March and October 2015. Strong El Niño conditions caused higher than normal water temperatures, affecting the number, location and distribution of large baleen whales within the study area. The team successfully tagged eighteen animals from four different species (fin whale, blue whale, Risso's dolphin, and bottlenose dolphin). The field team completed five full experimental sequences, including two with actual Navy ships (USS Lawrence and USS Russell) during normal ship training operations. In addition, in 2015 the team reconfigured the field setup to include three rigid hull inflatable boats (also called RHIBs), which allowed for increased adaptability and spatial coverage of the area. Analyses of collected data are in process.

The SOCAL BRS efforts have built upon previous BRS efforts at AUTEC in the Bahamas during 2007 and 2008, and in the Mediterranean Sea in 2009.

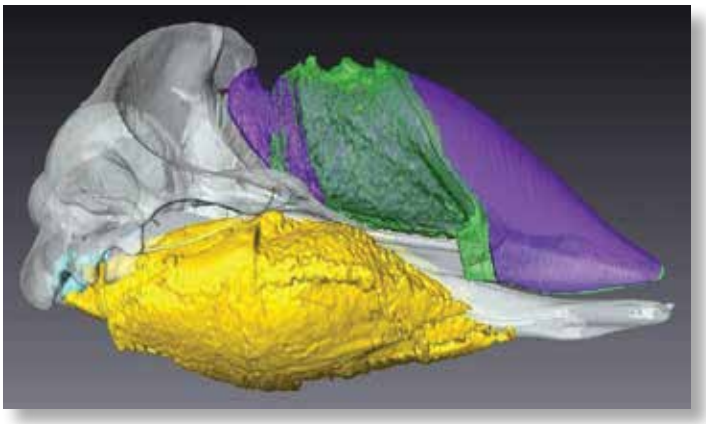
Primary Audiograms of Hearing in Baleen Whales

Project number: 11
Need addressed: N-0012-13 Hearing and Auditory System Information for Hearing-based Risk Criteria
Principal Investigator: Darlene Ketten, Woods Hole Oceanographic Institution

The level of impact on marine mammals associated with active sonar and underwater detonations is difficult to determine without a thorough understanding of how these animals hear and the relative effects of sounds at different frequencies on each species. The Navy currently relies on behavioral and other studies involving bottlenose dolphins and sea lions, as these species are relatively easy to work with in captivity. However, for species that are rare or difficult to keep in captivity, such as baleen whales or beaked whales, a different approach is needed.

The goal of this project is to determine how sound travels within the auditory system of baleen and beaked whales both on and beneath the ocean's surface, and 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 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.

New Starts

The three FY15 new start projects highlighted below focus on improving the knowledge base of hearing in marine mammals.

Behavioral Audiometry in Multiple Killer Whales

Project number: 14
Need addressed: N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species
Principal Investigator: Brian Branstetter, National Marine Mammal Foundation

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 will provide the first demographic hearing data from killer whales by measuring behavioral audiograms from five to eight participants that vary in age and gender. Additional subjects may become available during the course of the study. Audiograms will be 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 are the "gold standard" of hearing tests, leading to the most accurate audiometric measurements.

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Data from this study will more than double the number of individual killer whales that have been tested, as well as provide hearing data over a large age range of 12 to 49 years. This will help to determine accurate mid-frequency cetacean composite audiograms and weighting functions for Navy at-sea environmental compliance. This work is a follow-up to a 2014 cooperative project between Sea World San Antonio and U.S. Fleet Forces Command.

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

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

Project number: 20
Need addressed: N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species
Principal Investigator: Ron Kastelein, SEAMARCO (Sea Mammal Research Company Inc.)

A variety of Navy sonar sources are audible to harbor porpoises *(Phocoena phocoena)*, a small odontocete species that has a wide distribution area, acute hearing, and functional hearing over a very wide frequency range.

It is important to understand the difference between an animal hearing a sound and that sound causing an effect—either a behavioral effect or a physiological effect on hearing, known as a temporary threshold shift (TTS) or permanent hearing threshold shift (PTS). Based on the presently available information, neither TTS (especially for frequencies above 7 kHz) nor behavioral responses can be predicted for harbor porpoises due to exposure to specific signals of U.S. Navy relevance.

It is important to understand the difference between an animal hearing a sound and that sound causing an effect.

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

2. Establishing the dose-behavioral response relationship for playbacks of 53-C sonar sounds at 2.6% duty cycle in three Sea State noise conditions (Sea States 0, 4 and 6).

The TTS study also consists of two phases:

1. Establish which hearing frequency is most affected by several continuous pure tones above 8 kHz (i.e., shows the highest TTS).

2. Establish TTS growth curves (due to sound pressure levels) for each of the tested frequencies (1 hour exposures).

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.

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

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.

Passive Acoustic Monitoring (PAM) offers the Navy a powerful and beneficial tool to obtain density estimates for species of concern in situations where other methods (e.g., visual) are infeasible or prohibitively costly. The Navy's current, state-of-the-art PAM systems, however, generate huge volumes (many terabytes per year) of data and interpreting these data is not an easy task, and often requires subject matter experts.

For 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 mammals sounds.

The projects within this investment area focus on developing, testing, and evaluating existing or new PAM signal processing systems to detect and classify animals by sound and to estimate how many animals are present. This section includes summaries of the following six projects (three ongoing and three new starts):

- Simple Performance-characterized Automatic Detection of Marine Mammal Sounds
- Developing Automated Whistle and Click Detectors and Classifiers for Odontocete Species in the Pacific and Atlantic Oceans
- Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals

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- Passive Acoustic Density Estimation of Baleen Whales: Using Sonobuoys to Estimate Call-Rate Correction Factors
- Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data
- DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas.

Ongoing

Simple Performance-characterized Automatic Detection of Marine Mammal Sounds

Project number: 03
Need addressed: N-0020-13 Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data
Principal Investigator: Dave Mellinger, Oregon State University

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 Office of Naval Research, 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.

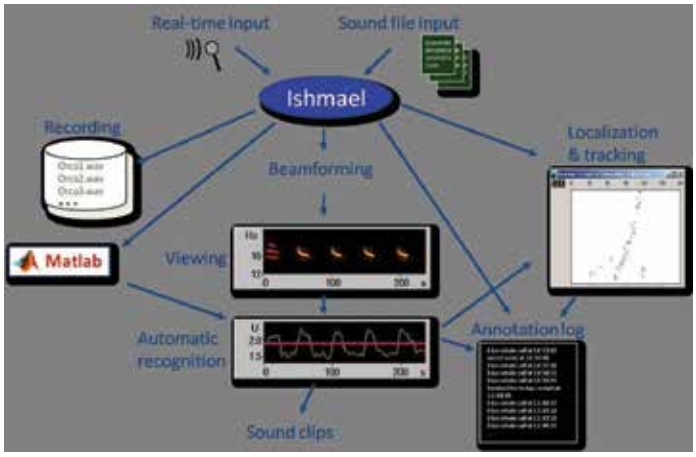
The detectors/classifiers currently in the PAM system database will be characterized and evaluated by testing them against sound files found in MobySound.org, a publicly accessible archive of sound recordings of over 35 marine mammal species. MobySound recordings have been annotated to indicate where (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.

The detectors/classifiers currently in the PAM system database will be characterized and evaluated by testing them against sound files found in MobySound.org.

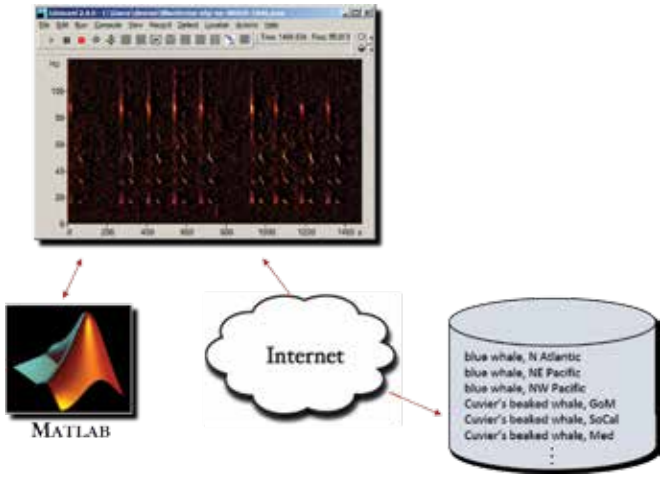
In FY15, the software interface within Ishmael was enhanced so that it could communicate seamlessly with MATLAB, a language widely used to easily implement detectors and classifiers. In addition, an online database archive for detectors/classifiers was built, but it is not yet fully populated for all species.

Work in FY16 will focus on completing the online database of detectors/classifiers for beaked, sperm, and baleen whales as well as a number of delphinids (small to medium cetaceans, such as pilot whales, dolphins, etc.). These detectors/classifiers will then be tested against the sound files in MobySound to provide performance information for each one. By early 2017, an Ishmael-to-database interface will be created to display detectors and performance data in Ishmael and make it simple to download and install any of the available detectors/classifiers.

This will be followed by documentation and training for Navy personnel and private (contractor) marine mammal observers as well as regulators who are involved in Navy passive acoustic data. Training will be provided by adding a new module to the existing Bio-Waves training course for passive acoustics technicians.



Components of Ishmael.



Ishmael's links to detector/classifier database, and to MATLAB for running the detectors/classifiers.

Stand-alone training on the new software will also be available.

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.

Having a system for marine mammal detection that is both straightforward to use and well-characterized will make adoption of acoustic monitoring faster, easier, and therefore more widespread within the Navy, enabling easier compliance with environmental law and practice.

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

Project number: 05
Need addressed: N-0020-13 Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data
Principal Investigators: Julie Oswald and Tina Yack, Bio-Waves, Inc.

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This LMR project is developing a suite of fully automated classifiers to identify and categorize the sounds produced by odontocetes.

This project is working to advance the science of automatic detection and classification by adding capabilities to existing software for acoustic analysis by developing a suite of fully automated classifiers to identify and categorize 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 Principal Investigators are working to develop classifiers that use information from whistles and clicks as well as variables related to location and acoustic behavior to classify acoustic encounters with odontocete species on several naval ranges. These classifiers will be incorporated into existing whistle classifier software called Real-time Odontocete Call Classification Algorithm (ROCCA). ROCCA currently is available as a module in the marine mammal passive acoustic data processing software program called PAMGuard. The updated classifiers will be made available for use in PAMGuard as well as in another widely used software package called Ishmael.

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 temperate Pacific Ocean (both areas funded by ONR), and a third for species in the northwestern Atlantic Ocean (funded by the LMR program).

In FY15, whistle and click feature vectors were created for the northwest Atlantic region. Collection, organization, and analysis of whistles, clicks and behavior/location data is also underway for the Hawaii and temperate Pacific zones. In 2016, the researchers will use LMR funding to integrate the new ROCCA classifiers into PAMGuard, and in 2017 will integrate the classifiers into Ishmael. A manuscript comparing and contrasting whistles and click information in the three targeted regions will also be produced.

Combining whistle, click, and context feature vectors to produce a final classification will provide a tool for efficiently and automatically processing the large datasets generated during PAM projects. New PAMGuard and Ishmael capabilities will be taught during Bio-Waves' annual Passive Acoustic Technology training course. User manuals will also be produced and a PowerPoint tutorial will be posted on the Bio-Waves and LMR web sites.

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

Project number: 08
Need addressed: N-0020-13 Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data
Principal Investigator: Tyler Helble, Space and Naval Warfare Systems Center Pacific

This project is drawing upon the Navy's larger sonar/radar signal processing community's expertise and their analytical methods and approaches, which are used to develop optimal detectors for signals of interest for active and passive sonar systems. These techniques are being applied to the PAM systems that the Navy uses to monitor marine mammal populations.

The team is focusing primarily on the Generalized Power Law (GPL) processor, the optimal detector for transient signals, or signals with unknown frequency content, location, duration and strength. The GPL processor has been used with great success in the collection of humpback whale data by autonomous High-frequency Acoustic Recording Packages (HARP) systems that are currently being used for PAM at several Navy training and testing ranges.

Conventional detection of humpback vocalizations is often based on the assumption that energy (square of the Fourier amplitude) is the appropriate metric. Power law detectors allow for a higher power of the Fourier amplitude, appropriate when the signal occupies a limited but unknown subset of these frequencies. Simply stated, sound in the ocean is rarely stationary, and a power law metric is a more accurate way of isolating and identifying specific sounds.

Raw counts of marine mammal call detections by themselves can be very misleading. They should be corrected for variability in environmental properties before any interpretations can be made. For instance, when ocean noise levels are very low, more humpback whales are detected. However, while the probability of detection rises during these time frames, the animals may very well have been present all along.

The GPL processor is able to detect weak transient whale vocalizations in the presence of considerable anthropogenic and biological noise. This has proven to hold true even during periods of U.S. Navy mid-frequency active sonar transmissions typical in training events. Any algorithms developed for GPL processing are constrained by the need for pre-processing adaptation to accommodate the noise environment at each location, as well as noise created by the platform itself. In addition, ocean bathymetry greatly influences PAM readings. For these reasons, the creation of a fully automated system is not feasible. This project will design a system that "calls out" potential signals of interest for examination by a human operator.

During FY15, researchers created and tested an auto-tuning algorithm for baleen whales using data from the Pacific Missile Range Facility.

In FY15, working closely with other LMR-sponsored project teams, researchers created an auto-tuning algorithm for baleen whales. The tuned algorithm was subsequently tested on data from the Pacific Missile Range Facility for five species: humpback, minke, sei/fin, blue and Bryde's whales. Probability of detection versus noise curves were created for humpback whales at three HARP locations over all seasons and sediment types.

At present, algorithms for detection and localization of humpback, Bryde's, minke, sei/fin are being used by Space and Naval Warfare Systems Center Pacific (SSC Pacific). GPL and Rapid Review software are being used by University of California San Diego's Whale Acoustics Laboratory for blue whale type D calls, humpback and minke whales, and is beginning to be used on grey and fin whales. Calibrated call methods will be transitioned to the National Marine Fisheries Service, and relevant technology transfer is in process for SSC Pacific, Naval Undersea Warfare Center, and Scripps Whale Acoustics Laboratory. At the close of FY15, environmental calibration of call counts was near completion for blue whale type D calls gathered from HARP data at the Southern California Offshore Range (SCORE).

Implementation of this technology at Navy sites will increase computational costs (and may require acquisition of additional computer resources), but will vastly reduce human operator time required to examine the passive acoustic recordings. Therefore, significant net cost (and time) savings are expected.

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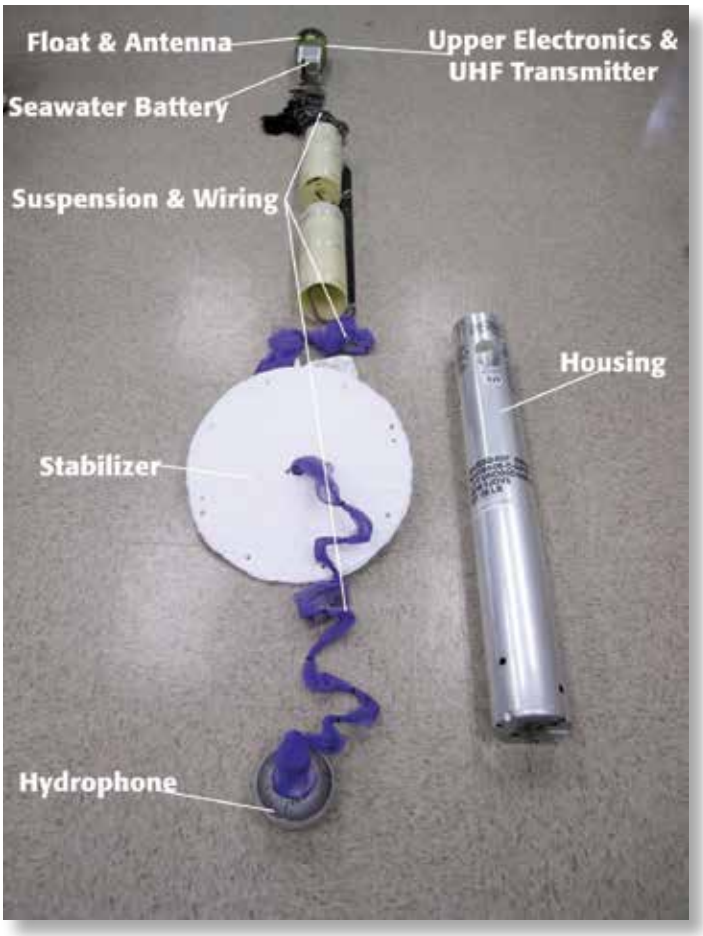
Humpback whale. NOAA/NMFS.

New Starts

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

Project number: 16
Need addressed: N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data
Principal Investigator: Shannon Rankin, Southwest Fisheries Science Center

This project will work to improve animal density estimates of baleen whales in the California Current and Navy's SCORE range by combining sonobuoy data with visual sightings to estimate the correction factor needed to convert call density data to whale density data. The sonobuoys used are equipped with signal processing technology that works in conjunction with PAMGuard, a widely used marine mammal passive acoustic processing program. The density of whales will be compared over the entire study area using visual line-transect survey methods during daylight hours and acoustic point-transect survey methods during night hours.



Parts of a SSQ-Q53F sonobuoy after being removed from its housing.

Sonobuoys offer several benefits for PAM. They are used extensively by the U.S. Navy, and surplus sonobuoys have proven valuable for detection and localization of baleen whales. Deployment of sonobuoys requires minimal experience and can be conducted from a variety of platforms (airplanes, helicopters, ships of various sizes), which allows for opportunistic monitoring. Data collection can be conducted in real-time, allowing for a short turnaround between identifying a need and obtaining data and density estimates for baleen whales in a given area.

Project team members are participating in a larger marine mammal survey being conducted by the National Oceanic and Atmospheric Administration (NOAA). Most of the costs of phase one were covered by NOAA, the Bureau of Ocean Energy Management, and Navy. The data analysis portion of this phase, now underway, is being funded by LMR.

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

Project number: 17
Need addressed: N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data
Principal Investigator: Ana Širović, University of California San Diego, Scripps Institution of Oceanography

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.

Team dual-deploying an acoustic and video tag on a blue whale. A. Allen; NMFS Permit 14534.

The project will develop spatially and temporally explicit density estimates for blue and fin whales in the Southern California (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 the Office of Naval Research (ONR), utilizing data from acoustic tag deployments from the SOCAL Behavioral Response Study, and will also 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.

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

Project number: 19
Need addressed: N-0077-15 Population Density Estimation from Passive Acoustic Monitoring Data
Principal Investigator: Len Thomas, University of St. Andrews

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 (SOAR). 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: the Cuvier's beaked whale and fin whale. The project will employ data and systems from both the SOCAL Behavioral Response Study and the Marine Mammal Monitoring on Ranges (M3R) projects.

The end products will be 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.

A group of Cuvier's beaked whales surface synchronously on a calm, clear day at SOAR. Gregory S. Schorr; NMFS Permit 16111.

Monitoring and Mitigation Technology Demonstrations

Demonstrate technologies that offer to enhance marine species monitoring capabilities.

The Passive Acoustic Monitoring 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 technology becomes available it could offer increased detection range performance, spatial resolution, and if successful, improved density estimation.

To ensure that monitoring efforts are keeping pace there is a need to analyze the performance and costs of existing PAM technologies and research, demonstrate and, if needed, propose and validate alternative PAM systems that could address shortcomings in existing systems.

The projects in this section are testing and demonstrating a number of PAM systems that could improve the Navy's ability to monitor for marine mammals in training areas. The following projects are summarized:

- Demonstration of High-performance PAM Glider and Profiler Float
- Technology Demonstration for Navy Passive Acoustic Monitoring
- Integrated Real-time Autonomous Passive Acoustic Monitoring System

Ongoing

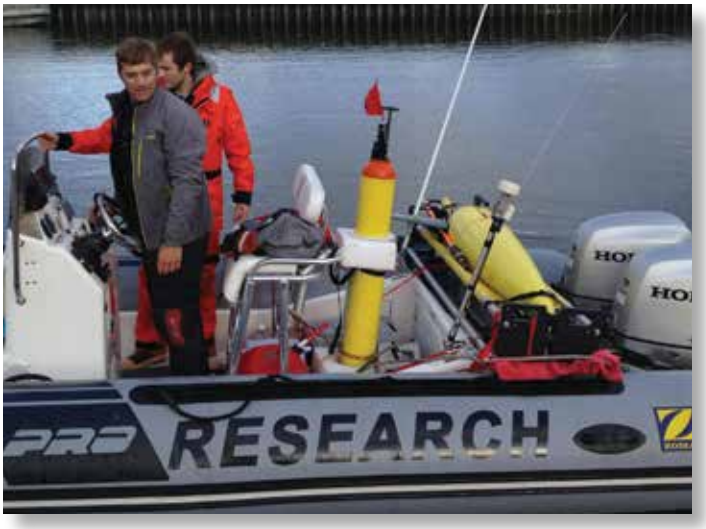
Demonstration of High-performance PAM Glider and Profiler Float

Project number: 04
Need addressed: N-0006-13 Demonstration of Remote Passive Acoustic Sensing Technology
Principal Investigator: Haru Matsumoto, Oregon State University (OSU)

This project is demonstrating two autonomous PAM platforms based on commercially available gliders and profiler floats—platforms which would allow the Navy to cost-effectively monitor marine mammals anywhere in the world including remote and non-instrumented training and testing areas.

Both platforms include an acoustic system that was developed by OSU with funding provided by the Office of Naval Research (ONR). The OSU PAM board is based on an advanced digital signal processor (DSP) and a low noise pre-amplifier that achieve a signal-to-noise ratio higher than 96 decibels. The electronic noise level of this system is well below the ambient noise level of a typical calm ocean, maximizing the listening range and detection performance

The PAM board installed in the Kongsberg Seaglider.



Acoustic Seaglider and QUEphone deployment off Washington. Two instruments were deployed from the 21-ft RHIB.

in a wide variety of ocean conditions. This system's listening capability covers the frequency range of almost all cetaceans except for porpoises.

The DSP system has already been used in previous work sponsored by ONR with an APEX-type float from Teledyne Webb Research. This project is comparing the APEX float, known as a QUEPhone, with the Seaglider from Kongsberg. Both platforms are buoyancy-driven, deep-diving vehicles capable of descending to 1,000 meters (glider) and 2,000 meters (float). While gliders can be steered remotely, profiler floats simply drift with the ocean current. The advantage of the float lies in its comparatively low cost, 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 likely impact the passive acoustic performance of the systems and it is the goal of this project to examine and evaluate these factors. Earlier tests have indicated that the deeper-diving float has increased beaked whale detection capabilities, so an additional goal is to collect a more robust acoustic data set for the presence, distribution and density estimation of beaked whales.

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In October 2014, the Seaglider underwent a successful engineering test off the coast of Newport, Oregon. The system met performance parameters in terms of power usage and self-noise. A serial interface error was discovered and corrected.

In April 2015, a two-week test was conducted to compare the capabilities of both platforms to those of a bottom-moored High-frequency Acoustic Recording Package (HARP) at the Quinault Training Range (QUTR) in Washington State. Unfortunately, a delay in recovering the HARP data prevented the timely comparison of the float and the glider with the HARP data. However, data analysis of the two platforms revealed that the Seaglider was noisier than the QUEPhone, but the Seaglider collected more data because it remained in the high animal-density area. HARP data are expected to be recovered early in 2016 when data from each of the platforms will be compared.

Both platforms were demonstrated in December-January 2015-16 in coordination with a Marine Mammal Monitoring on Navy Ranges (M3R) program event.

Both platforms were demonstrated in December-January 2015-16 in coordination with an M3R program event at the SCORE. The demonstration lasted 14 days, and data analysis will require approximately three months.

A PAM board draft manual has been published online. At the end of this project, a final manual will be posted, and a detailed report will be issued comparing the performance of each system with the HARP and M3R systems. This information will allow potential end users, including the Navy, to buy the PAM board and hydrophone and to send it to the corresponding manufacturer for installation on a float (Teledyne Webb) or Seaglider (Kongsberg).

This technology will enable the Navy to monitor marine mammals cost-effectively in real time, in areas of interest where cabled hydrophone arrays are not available or poor weather conditions prohibit ship-based visual observation.

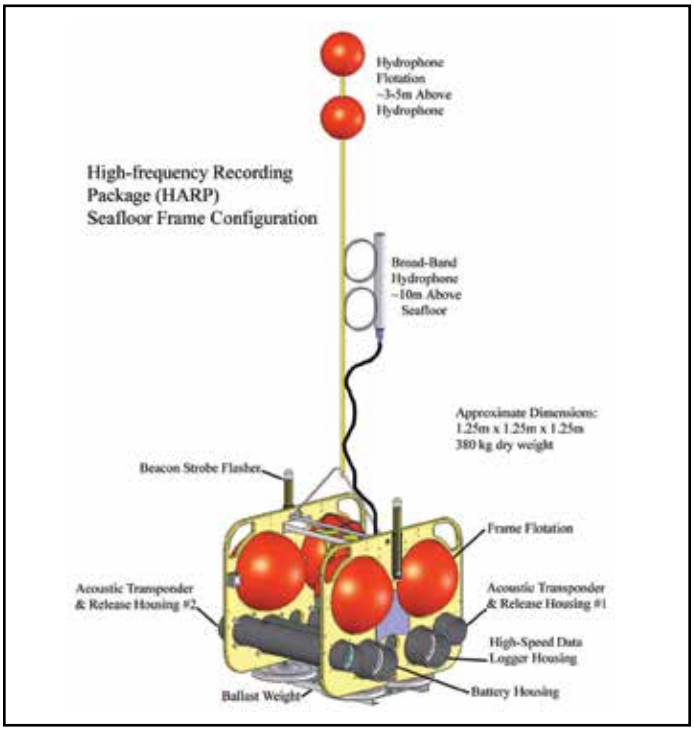
Technology Demonstration for Navy Passive Acoustic Monitoring

Project number: 07
Need addressed: N-0006-13 Demonstration of Remote Passive Acoustic Sensing Technology
Principal Investigators: John Hildebrand and Sean Wiggins, Scripps Institution of Oceanography

The High-frequency Acoustic Recording Package (HARP), currently used on several Navy ranges, is a state-of-the-art PAM recording system that features high bandwidth (up to 160 kHz) and large data storage (5 terabytes (TB)) combined with low power requirements. However, evolving mass storage capabilities have rendered the current HARP storage media obsolete. This project team is upgrading the deployed HARP systems with new storage media thereby increasing the storage capacity and processing speed of the Navy's existing HARP systems.

Original HARP data storage was based on Integrated Drive Electronics (IDE), a standard electronic interface for disk storage devices known by the American National Standards Institute as Advanced Technology Attachment (ATA).

More recently the Serial ATA (SATA) interface has become the industry standard. SATA offers several advantages over the parallel ATA interface—reduced cable size and cost, along with faster and more efficient data transfer. The current HARP system has a maximum storage capacity of 5TB or 10 TB compressed storage. Once the SATA interface is installed, storage capacity will be increased to 16 TB (32 TB compressed) based on currently available hard disk drives. It is anticipated that this capacity will increase as disks with larger capacities become available.



The HARP seafloor frame configuration was developed by Sean Wiggins and John Hildebrand at Scripps Institution of Oceanography.

The modular nature of the HARP electronics allows for the upgrade of a select set of electronics boards rather than having to replace the entire system. Upgrade 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. Navy users include Fleet and System Command Marine Species Monitoring program managers and the related NAVFAC offices that execute these programs.

In FY15, the team tested the SATA at sea, and subsequently installed the interface in HARP systems at the Southern California Offshore Range and the Gulf of Alaska range.

In FY15, the team tested the SATA at sea, and subsequently installed the interface in HARP systems at the Southern California Offshore Range and the Gulf of Alaska Range. Data analysis was completed in September 2015, and reporting

is due to be completed by March 2016. Next steps are to install the SATA drives in HARP systems at the Atlantic Fleet Training and Testing areas and the Hawaii Range Complex. Funding for this project was also provided by the Atlantic and Pacific Fleets as well as ONR to complete all Navy HARP system upgrades by the spring of 2016.

Integrated Real-time Autonomous Passive Acoustic Monitoring System

Project number: 12
Need addressed: N-0006-13 Demonstration of Remote Passive Acoustic Sensing Technology
Principal Investigators: Phil Abbot and Vince Premus, Ocean Acoustical Services and Instrumentation Systems, Inc.

This project is leveraging hardware and software that the Principal Investigators have developed under ONR sponsorship over the past five years for the purpose of autonomous acoustic surveillance using Autonomous Undersea Vehicles (AUV).

This approach utilizes new acoustic sensor and digital signal processing (DSP) technology, as well as existing vehicle hardware developed and maintained by the Woods Hole Oceanographic Institution. These sensor and DSP technologies have previously been demonstrated using Slocum 100 and G2 gliders as an AUV. This project team is utilizing a self-propelled REMUS AUV, which can travel faster than the other platforms—therefore covering more ground—and has the battery capacity to support sensor and DSP deployment for several days. As it is self-propelled, the REMUS can also operate in the presence of currents, following any predetermined course.

The Integrated, Real-time Autonomous PAM (IRAP) system consists of a REMUS AUV, integrated with the OASIS low- to mid-frequency (LF/MF) sensor and a High Frequency (HF) sensor. Both sensors include onboard DSPs for the autonomous detection, classification, localization, and tracking (DCLT) of vocalizations from lower frequency baleen whales and higher frequency beaked whales. The sensors may be used independently or together.

The objective of this project is to integrate and demonstrate the technology over the course of three years. Now in its second year, the project is proceeding on schedule. Toward the end of FY14, an end-to-end engineering test was conducted off Cape Cod, after which the software was improved for real-time capability.

The LF sensor was integrated and a local test performed off the Massachusetts coast in April and June 2015. The integration and humpback whale classifier were validated during this test.

REMUS being deployed during a technology test. Mandy Shoemaker.

Next, the HF sensor for beaked whales was integrated into the system, and performance of the IRAP device was tested in Monterey Bay in concert with scientists from the Naval Postgraduate School. To quantify system performance, recorded signals of beaked and humpback whales were used.

Performance of the IRAP device was tested in Monterey Bay in concert with scientists from the Naval Postgraduate School.

The HF sensor performed as expected with no false alarms. However, it was noted that further assessment needs to be done regarding the transmission loss of the device during acoustic communication duty cycles. The frequency between duty cycles will be decreased on the next deployment.

The LF sensor on the IRAP device performance was quantified for several factors, including the performance of the joint detector-classifier in terms of holding time ratio versus range, and false alarm rate. The LF sensor was found to capture the animal vocalizations in an area much larger than a single hydrophone (1,880 square kilometers (sq. km) versus 28 sq. km).

The IRAP device will be tested in February 2016 at Pacific Missile Range Facility in concert with the Submarine Commanders Course. This will provide an opportunity to collect LF and HF whale vocalizations concurrently with data from multiple naval tactical sonar systems.

The system will demonstrate the ability to track low-frequency baleen whales and high-frequency beaked whales while simultaneously monitoring the operation of mid-frequency active sonar. Due to its mobility and broadband frequency coverage, the IRAP system has already demonstrated improved detection coverage relative to single-channel systems.

Fin whale. Brenda K. Rone; NMFS Permit 15330.

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. When different techniques are used, for example in hearing threshold measurements, resulting data might not be consistent. These potential discrepancies raise the need for agreement on data standards.

The four projects currently within this investment area are addressing different aspects of data standards. The first is an ongoing project seeking to address data processing. The remaining three projects, all new starts, are focused on comparability of results from different methodologies and on standardizing protocols. The following projects are summarized:

- Database and Metrics for Testing Automated Signal Processing for Passive Acoustic Monitoring
- Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database
- Jawphone Simulations to Maximize the Utility of Psychoacoustic and Auditory Evoked Potential Experiments
- Acoustic Metadata Management for Navy Fleet Operations

Ongoing

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

Project number: 06
Need addressed: N-0020-13 Demonstration and Evaluation of Platform-independent Improvements to Automated Signal Processing of PAM Data
Co-Principal Investigators: John Hildebrand, Simone Baumann-Pickering, and Ana Širović, Scripps Institution of Oceanography; Marie Roch, San Diego State University

The HARP continuous monitoring system, one system currently used on several Navy ranges, can store up to 32 terabytes (compressed storage) of data. (This capacity was recently upgraded. See the related project, "Technology Demonstration for Navy Passive Acoustic Monitoring.")

Processing such a massive amount of data is a difficult and time-consuming task and requires trained users. This project intends to simplify the data management process so that non-expert users can access and process the data gathered by monitoring systems.

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The current state-of-the art for processing large PAM data sets in the Navy is a hybrid between manual scanning of the data and automatic call detection. This 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.

The project team will develop metrics for assessing the performance of existing and future data processing algorithms for PAM data. To do so, the team will construct marine mammal sound datasets specific to a particular Navy training and testing area, then compose a standardized set of metrics to assess the performance of both existing algorithms and potential new algorithms.

During FY15, the project team compiled an extensive set of training and test data based on acoustic recordings already collected at naval training areas on the west coast.

During FY15, the project team compiled an extensive set of training and test data based on acoustic recordings already collected at naval training areas on the west coast. The team completed two datasets (high frequency and low frequency) that were focused on particular species and signal types, and sampled the range of variability of the signal, the ocean noise environment in which the signals occur, seasonal variables, and the contribution of variations in the recording system. The high frequency dataset focused on labeling encounters of sperm whales, Baird's beaked whales, Cuvier's beaked whales, white-sided dolphins, harbor porpoises, Risso's dolphins, and an unidentified cetacean category, while the low frequency dataset focused on blue whales and fin whales.

The data were shared with the marine mammal researcher community as part of the 7th International Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals Using Passive Acoustics, for use in developing automatic algorithms related to call detection and classification. This protocol follows the well-developed path of the Advanced Processor Build program utilized in the Anti-Submarine Warfare community.

The original plan included additional datasets for the east coast and central/western Pacific; however, since the west coast dataset took longer than originally anticipated, the revised plan is to direct all remaining efforts toward creating metrics for evaluating algorithms.

In addition to the datasets described above, an ongoing 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. In FY15, three main issues were discussed by the metrics committee:

- What is ground truth for testing algorithms?
- Are receiver-operator curves (ROC)/detection error trade-off (DET) curves optimal?
- What are the important scenarios to evaluate first?

Work by the metrics committee will be ongoing through FY16. These metrics will then 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 a comprehensive dataset of marine mammal calls for use in the development of 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.

New Starts

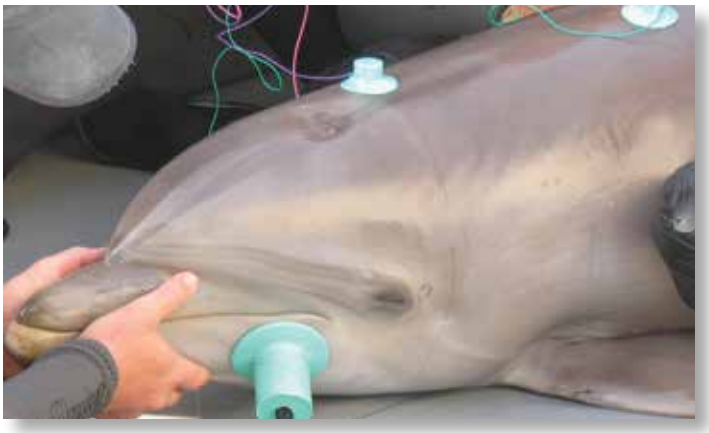
Standardization of AEP Audiometry Methods to Ensure Comparable Data Inclusion in a National Marine Mammal AEP Database

Project number: 13
Need addressed: N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species
Principal Investigator: Dorian Houser, National Marine Mammal Foundation

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 (AEPs), can be quickly measured in subjects with minimal subject cooperation.

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 has 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 project will standardize hearing threshold measurement methods used in toothed whales (odontocetes) and increase species representation and sample sizes in hearing threshold estimates to reduce uncer-



Bottlenose dolphin undergoing an AEP hearing test.

tainty in hearing range analyses used by Navy planners. Efforts include developing and promoting a standardized methodology for the collection and reporting of audiometric information from odontocetes through AEP methods. Following completion of the standard, the portable AEP system currently in use, called the Evoked Response Study Tool (EVREST), will need to be reprogrammed according to the consensus methodologies determined through the standardization process.

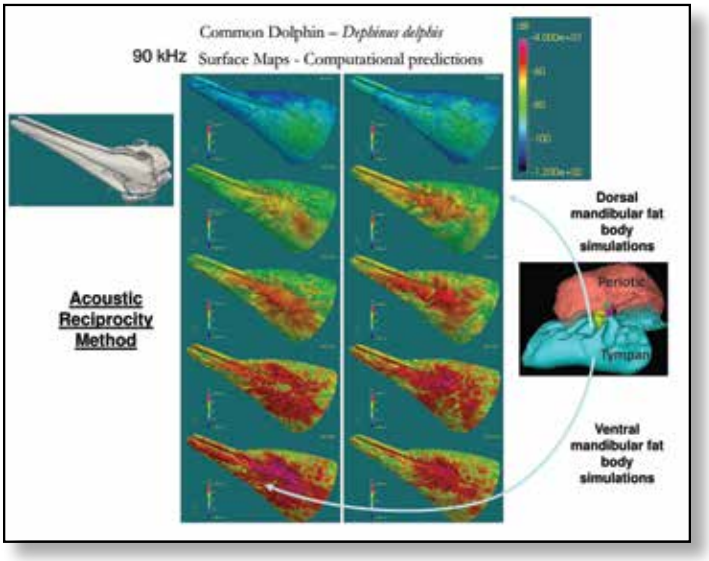
Data collected from wild odontocetes with the AEP systems, under standardized methods, will be incorporated into the national AEP database and access for queries to the database will be made available to Navy environmental planners.

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

Project number: 15
Need addressed: N-0096-15 Hearing Measurements in a Broad Range of Marine Mammal Species
Principal Investigators: Ted Cranford, San Diego State University; Petr Krysl, University of California, San Diego

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 (AEPs), can be quickly measured in subjects with minimal subject cooperation. To date, however, basic hearing measures (AEP or behavioral) have only been compiled on a small number of animals, and interpreting AEP results may be more complicated when a device called a jawphone (suction cup containing a transducer) is used. The placement, frequency selection, and other parameters of the jawphone can affect 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. Small changes in the placement of a simulated jawphone can cause large amplitude differences (several decibels) by the time the sounds reach the ears.



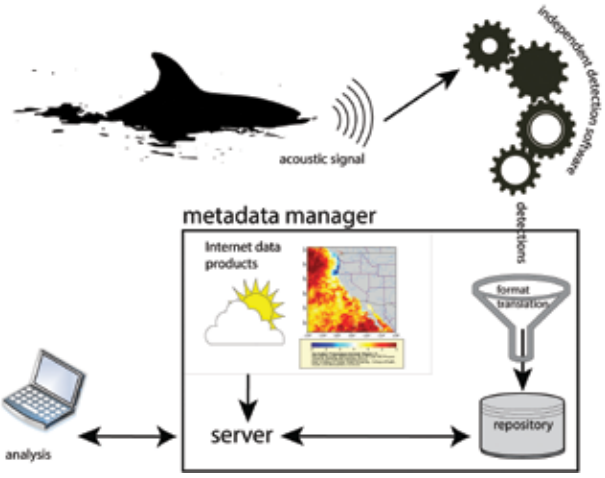
This project will use a computational approach to identify the mechanism(s) by which jawphones stimulate hearing when they are used to gather data on marine mammal auditory capabilities. The methodology is based on finite element modeling techniques, where high-resolution computerized tomography (CT) 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 compile sensitivity maps that identify the optimal locations for jawphone placement in three dolphin species. These maps can be used to design and evaluate AEP-based hearing tests, guiding jawphone placement in order to minimize errors due to variable response sensitivity to the location of the transducer on the animal's skin.

This modeling environment gives researchers the ability to conduct "virtual experiments" to investigate basic mechanisms of hearing and sound production, and to simulate exposure levels at sound pressures that would be impossible or unethical with live animals. These results will be helpful in the design and evaluation of past and future AEP hearing tests, will significantly reduce lifecycle costs of physical experimentation, and have the potential to reduce environmental impacts.

Acoustic Metadata Management for Navy Fleet Operations

Project number: 18
Need addressed: N-0088-15 Marine Species Monitoring Data Collection Toolkit Development
Principal Investigator: Marie Roch, San Diego State University

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, or with developing inter-agency marine bio-data standards and other established international standards for biogeographic data.



Overview of metadata management 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. (Sea surface height anomaly image courtesy NOAA Southwest Fisheries Science Center Environmental Research Division.)

The Navy has an immediate need for improved data collection platform technology to meet monitoring requirements.

This project will expand development of Tethys, a passive acoustic monitoring metadata database sponsored by National Oceanographic Partnership Program. Tethys incorporates the expertise of PAM personnel at National Oceanic and Atmospheric Administration (NOAA) 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. The system provides a standard that can be implemented on any system, and there is broad interest in transitioning what is becoming a community standard into an official one.

The project team will strengthen 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 performance as the existing databases continue to grow in size, and further development of the program's

schemata for localization. These efforts will improve its utility for long-term Navy monitoring data management and support Navy mitigation efforts.

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, and portions of the project are currently being funded by the LMR program while others are being funded by BOEM.

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 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. It currently includes one ongoing project, summarized below.

Ongoing

The Effects of Noise on Marine Mammals

Project number: 10
Need addressed: N-0001-13 Assessing and Mitigating the Effects of Noise on Living Marine Resources
Principal Investigators: Christine Erbe, Curtin University; Dorian Houser, National Marine Mammal Foundation

The single most cited resource for information on the effects of noise on marine mammals is a book that was published in 1995 (Marine Mammals and Noise, Academic Press, San Diego). This book 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.

Given the pressing and shared need to update this book and to make this information available via the internet, this is a leveraged project with funding from the Office of Naval Research, National Oceanic and Atmospheric Administration, and Joint Industry Program.

The tasks to be undertaken during the LMR portion of this effort include:

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.

Project team members each have their own research database from which to gather information. The team utilized these databases as well as articles and reports from the scientific community and "grey" literature (reports that were not published in scientific journals) to develop a bibliographic database. The database was constructed in July 2015, and is approximately 75 percent populated with 4,747 papers and reports. 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 bioacoustics 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:

1. Completed a review of the literature on sound production
2. Generated a tabular summary of acoustic characteristics by taxon
3. Generated a taxonomic breakdown
4. Summarized regional differences
5. Captured spectrograms of the best documented and illustrative vocalizations
6. Provided a critical summary of source levels and call structure and regional differences.

Researchers will continue to add data to the database throughout 2016. At the close of the project in 2017, the team will submit a manuscript for publication and make the completed database publicly available via the internet.

This project will better enable 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.

Partnerships

Working with other organizations on related projects helps to leverage funding, expand investigation options and draw on additional expertise. Examples of partnership efforts are discussed below.

ESTCP: Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales

Principal Investigators: Cara Hotchkin, NAVFAC Atlantic; Mark Baumgartner, Woods Hole Oceanographic Institution; Sofie Van Parijs and Peter Corkeron, Northeast Fisheries Science Center

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, moored buoys)

2. Validating real-time acoustic detections using audio recorded in-situ and airplane-, ship-, and land-based visual observations

3. Developing best practices for integrating real-time acoustic detections from autonomous platforms into persistent visual monitoring.

A Sei whale observed north of Oahu in 2007. CETOS Research Organization; NMFS permit #1039–1699.

Successful demonstration and validation of this technology may provide long-term reduction in analytical effort and improved efficiency of existing monitoring technologies by including real-time detection information.

The first deployments of the autonomous platforms began in May 2015, with the Slocum and Wave gliders. 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. The four species of baleen whales that are the project focus were detected within the first few days of the deployment period. Over the course of the next two years, co-located visual monitoring from ships, aerial surveys, and land-based observation platforms will provide data on the visual and acoustic detection rates for these endangered species.

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

Principal Investigator: Michael Richlen, HDR Environmental

OPNAV N45 has funded the project "Survey Software Toolkit for Data Collection, Data Workflow, and Data Delivery." The data collection toolkit is intended to streamline survey data collection so that all aspects of the workflow become more efficient. The Navy's Marine Species Monitoring program and the LMR program will work collaboratively to provide guidance during development and testing of the toolkit in order to make sure that the product is meeting the Navy's needs.

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The Behavioral Response Research Evaluation Workshop (BRREW)

Principal Investigators: Len Thomas and Catriona Harris from the University of St. Andrews

This effort was co-sponsored by ONR, LMR, and National Marine Fisheries Service and was held in Monterey, CA from 21-23 April 2015. The workshop was undertaken to evaluate the return on investment of current U.S. Navy-funded programs, identify the data needs and the contributions of current research programs to meeting those data needs, and determine the ability to meet outstanding data needs given the current state of the technology.

A questionnaire was sent out to researchers before the workshop to elicit input of the current state of knowledge in key areas of behavioral response research, the research gaps, and suggested pathways to fill those gaps. The results of the questionnaire were then synthesized and discussed as a group during the workshop.

The workshop report is available at: http://hdl.handle.net/10023/7741. See "Publications from LMR-funded Projects" section, page 48, for report citation.

Sonobuoy Liaison Working Group

The Sonobuoy Liaison Working Group (SLWG) plays 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.

The Sonobuoy Liaison Working Group plays an important role in supporting sonobuoy allocations to marine mammal research and monitoring.

In FY13, the evaluation process for marine mammal related requests for sonobuoys was assigned to the LMR program. In FY15, the LMR program worked with the SLWG to come up with an annual schedule and refine the request process. Beginning in FY16, a more formalized process will be implemented, which will include a Sonobuoy Request Form for researchers to fill out when making their requests. LMR was able to allocate 400 sonobuoys in FY15 to various marine mammal research and population survey projects.

Conference on the Effects of Noise on Aquatic Life

The LMR program is one of the sponsors for the 4th International Conference on the Effects of Noise on Aquatic Life, Dublin 2016, which brings together scientists, regulators, environmentalists, and people from industry to learn about and discuss issues related to the effects that man-made noise has on aquatic organisms. For more information, please visit the conference website at http://www.an2016.org/index.html.

Completed Projects

The LMR-funded project that was completed in 2015 is listed below, along with a brief project description and overview of accomplishments.

Electrophysiological Correlates of Subjective Loudness in Marine Mammals

Project number: 09
Need addressed: N-0012-13 Hearing and Auditory System Information for Hearing-based Risk Criteria
Principal Investigator: James Finneran, Space and Naval Warfare Systems Center Pacific

The original purpose of this project was to explore the use of electrophysiological measurements to obtain hearing data for the design of marine mammal weighting functions. The goal was to emphasize weight (noise) according to susceptibility at each frequency. A feasibility study was conducted where sounds were delivered to dolphins and sea lions while brain activity was simultaneously monitored via surface electrodes. Auditory evoked potentials (AEPs) were measured at a variety of sound frequencies and levels, and the relationships between acoustic parameters (i.e., frequency and amplitude) and AEP features (i.e., response amplitude and latency) were analyzed. Analyses of these data demonstrated that the AEP methods did not provide a reliable prediction of subjective loudness, especially at low frequencies where data are critical for the design of Navy weighting functions.

In late 2014 the goal of this project was updated to focus on investigating the potential reasons why AEP methods were not reliable at low frequencies. Research conducted during 2015 identified the primary origin of AEPs as the base of the cochlea. AEPs from various noise bursts of varying durations and with differing levels of background noise were measured in dolphins and sea lions over the course of the year. The main finding confirmed that low frequency thresholds cannot be determined with AEP methods. The reason is that while both the low and high frequency waves travel through the ear canal's basal membrane, the

longer low frequency waves pass by the high frequency regions first and they excite high-frequency areas before reaching the low frequency sensors. Therefore, low frequency stimuli produce both low and high frequency AEPs. The research team also determined that equal latency contours (reaction time measurements) provided limited benefit beyond auditory thresholds (audiograms).

The data gathered in this project will guide the derivation of auditory weighting functions in the acoustic effects analyses sections of Navy environmental documents. The data will be applicable to all Navy environmental documents analyzing acoustic effects of tonal sounds (e.g., sonars) and broadband noise sources, allowing for more realistic predictions of the effects of Navy sonars and explosive sources on marine mammals. The findings of this project will be disseminated through presentations at scientific conferences and publication in peer-reviewed scientific journals, and technical reports. Citations for the peer-reviewed publications can be found in the section "Publications from LMR-funded Projects" at the end of this report.

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LOOKING AHEAD TO 2016

Looking Ahead to 2016

For FY16 we will continue to evolve and refine how we select, manage and transition projects. We will continue to provide the PIs feedback to guide each project to better fit the need they are trying to address. For moving technologies out of demonstration/validation into implementation, we will focus on identifying and developing transition pathways and agreements that would lead to successful integration into the Navy marine species monitoring program efforts.

We look forward to initiating new projects during FY16. Projects will be selected from proposals received in response to the following two key needs:

1. Behavioral Response Research to Study the Effects of Sound on Marine Mammals. Two primary topics within this need are first, focusing on behavioral response research to improve our understanding of the potential effects from Navy training and testing activities, and second, demonstrating tag technologies that can record animal movement and behavioral responses over a longer-term duration (e.g., weeks to months).

2. Marine Species Hearing Research Related to the Acoustic Effects Criteria. Three topics within this need are: audiograms of hearing capability in marine species that have limited data available or have not been previously studied; hearing research to study temporary threshold shift (TTS) at multiple frequencies for marine species; and effects to fish from the detonation of explosive devices.

These needs were included in the BAA and are the basis for project proposals and project selection.

In FY16 we again will work to identify and address the Navy's research needs to improve the understanding of the occurrence, exposure, response, and consequences to marine mammals from Navy at-sea training and testing activities. Needs identified in FY16 will drive project evaluations for FY17 projects.

We anticipate broadening collaboration with other programs and agencies, including ONR, BOEM, NMFS and NPS, to build on shared interests and more effectively leverage investments to achieve common goals.

As always, we will maintain our ongoing efforts to improve our internal management processes to ensure that our projects are effectively executed.

For the most up-to-date program schedule and information, visit our web site at www.lmr.navy.mil.

Cuvier's Beaked Whale. Erin Falcone; NMFS Permit 16111.

Publications from LMR-funded Projects

Included here is a list of publications from 2015 that were partially or fully funded by the LMR program. These publications are of great value to the Navy's at-sea environmental compliance process and directly feed into the NEPA, MMPA, and ESA compliance documentation.

For a list of publications from 2013 and 2014, please see The LMR Program Report: 2014, available at www.lmr.navy.mil.

Baumann-Pickering, S., Simonis, A., Oleson, E., Baird, R., Roch, M., Wiggins, S. (2015). False killer whale and short-finned pilot whale acoustic identification. Endangered Species Research, 28:97-108.

Finneran, J.J. (2015). Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. The Journal of the Acoustical Society of America, 138:1702-1726.

Finneran, J.J., Mulsow, J., Houser, D.S., and Burkard, R.F. (2015). Place specificity of dolphin auditory evoked potentials assessed with high-pass masking noise. The Journal of the Acoustical Society of America, 137:2219.

Friedlaender, A. S., Goldbogen, J. A., Hazen, E. L., Calambokidis, J., Southall, B. L. (2015). Feeding performance by sympatric blue and fin whales exploiting a common prey resource. Marine Mammal Science 31(1):345-354.

Goldbogen, J. A., Hazen, E. L., Friedlaender, A. S., Calambokidis, J., DeRuiter, S. L., Stimpert, A. K., Southall, B. L. (2015). Prey density and distribution drive the three-dimensional foraging strategies of the largest filter feeder. Functional Ecology, 29:951–961.

Harris, C.M. and L. Thomas. (2015). Status and future of research on the behavioral responses of marine mammals to U.S. Navy sonar. CREEM Technical Report 2015-3, University of St. Andrews.

Hazen, E., Friedlaender, A., Goldbogen, J. A. (2015). Blue whales change their foraging strategies relative to prey density. Scientific Advances, e1500469.

Helble, T. A., Ierley, G. R., D'Spain, G. L., Martin, S. W. (2015) Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Facility.. The Journal of the Acoustical Society of America, 137:11.

Mulsow, J., Finneran, J. J., Schlundt, C. E. (2015). Equal-latency curves and auditory weighting functions for bottlenose dolphins (*Tursiops truncatus*) and California sea lions (*Zalophus californianus*). The Journal of the Acoustical Society of America, 137:2219.

Mulsow, J., Schlundt, C. E., Brandt, L., Finneran, J. J. (2015). Equal latency contours for bottlenose dolphins (*Tursiops truncatus*) and California sea lions (*Zalophus californianus*). The Journal of the Acoustical Society of America, 138:2678.

Roch, M. A., Stinner-Sloan, J., Baumann-Pickering, S., Wiggins, S. M. (2015). Compensating for the effects of site and equipment variation on delphinid species identification from their echolocation clicks. The Journal of the Acoustical Society of America, 137:22-29.

Schorr, G. S., Falcone, E. A., Moretti, D. J., Andrews, R. D. (2015). Rebuttal to the Formal Comment on Schorr et al. (2014) submitted by Tyack et al. (2015). PLoS ONE, 10(12):e0142437.

Southall, B. L., Calambokidis, J., Moretti, D., Stimpert, A., Douglas, A., Barlow, J., Keating, J., Rankin, S., Southall, K., Friedlaender, A., Hazen, E., Goldbogen, J., Falcone, E., Schorr, G., Gailey, G., Allen, A. (2015). Project report: Biological and Behavioral Response Studies of Marine Mammals in Southern California, 2014 (SOCAL-14).

Stimpert, A. K., DeRuiter, S. L., Falcone, E. A., Joseph, J., Douglas, A. B., Moretti, D. J., Friedlaender, A. S., Calambokidis, J., Gailey, G., Tyack, P.L., & Goldbogen, J. A. (2015). Sound production and associated behavior of tagged fin whales (*Balaenoptera physalus*) in the Southern California Bight. Animal Biotelemetry, 3, 1-12.

Van Parijs, S. M., Baumgartner, M., Cholewiak, D., Davis, G., Gedamke, J., Gerlach, D., Haver, S., Hatch, J., Hatch, L., Hotchkin, C., Izzi, A., Klinck, H., Matzen, E., Risch, D., Silber, G.K., Thompson, M. (2015). NEPAN - A U.S. Northeast Passive Acoustic Sensing Network for Monitoring, Reducing Threats and the Conservation of Marine Animals. Marine Technology Society Journal 49(2):70 – 86.

Acronym Table

ACRONYM	DEFINITION
ABR	Auditory brainstem response
AEP	Auditory evoked potentials
ATA	Advanced Technology Attachment
AUV	Autonomous Undersea Vehicles
BAA	Broad Agency Announcement
BOEM	Bureau of Ocean Energy Management
BRS	Behavioral Response Study
CT	Computerized tomography
DCLT	Detection, classification, localization, and tracking
DET	Detection error trade-off
DSP	Digital signal processor/processing
EIS	Environmental Impact Statement
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
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
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
QUTR	Quinault Training Range
RDT&E	Research, development, test and evaluation
ROC	Receiver-operator curves
ROCCA	Real-time Odontocete Call Classification Algorithm
SATA	Serial Advanced Technology Attachment
SCORE	Southern California Offshore Range
SME	Subject matter expert
SOAR	Southern California Anti-Submarine Warfare Range
SOCAL	Southern California
SSC Pacific	Space and Naval Warfare Systems Center Pacific
SYSCOM	System Command
TB	Terabytes
TRC	Technical Review Committee
TTS	Temporary threshold shift

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