
LMR
U.S. NAVY'S LIVING MARINE RESOURCES
PROGRAM REPORT
2019
SCIENCE • STEWARDSHIP
livingmarine
RESOURCES
NAVY READINESS
June 2020

2019 LMR Program Report

STATUS OF THE LIVING MARINE RESOURCES PROGRAM

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Marine mammal photos that do not include a credit/permit number are from stock photo services.
Most headshots are by photographer Kenny Backer, Oxnard, CA.

We are excited to share with you the 2019 Living Marine Resources (LMR) program annual report. Throughout the past year, the program and all of its participants continued their valuable work to support the Navy's ability to train, test and be mission-ready. Please see the Environmental Compliance Overview section (page 8) to learn more about how the LMR program supports the Navy's at-sea environmental compliance process.

The LMR program was managing 33 projects during 2019, all carefully selected to meet specific Navy-defined needs and provide additional scientific credibility to the Navy's environmental compliance analysis. Of the 33 projects, we initiated eight new projects and had 18 ongoing. Seven were completed during 2019 and are being transitioned to the end users.

This year LMR broadened our collaboration with other research programs. We entered a new partnership with the Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML), which was established by the Subcommittee on Ocean Science and Technology (SOST) to leverage other agencies' common interests to invest in research on mysticete hearing. This is a challenging research topic that is difficult for any one agency to tackle alone. By working together, we are able to pool our resources to gain further insight into what the potential impacts may be to large whales. For more information on this partnership, see the SOST ITF-ONML overview in the partnership section (page 105). For highlights of the two SOST ITF-ONML projects that LMR is managing, see pages 59 and 61 in the Program Portfolio, Investment Area 1. In another collaboration initiative, LMR was awarded three Phase 1 technology development projects under the Small Business Innovative Research (SBIR) program. The projects will expand our utility of unmanned underwater vehicles (UUV) to detect marine mammals in waters difficult to reach and survey. If successful, this will allow the Navy's Marine Species Monitoring program to extend their reach, and survey larger areas in a cost-effective manner.

We also want to share highlights from two of the seven completed projects to provide a sense of the scope of our work. One of these, Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises (Project 20, page 28), obtained critical data on the harbor porpoise hearing function related to Navy sonar. These data help us to develop a more robust scientific basis for estimating the effects of Navy training and testing on harbor porpoises. By the close of 2019, this project has produced six publications, with two more forthcoming in 2020. These publications provide Navy planners with the information needed to refine the criteria and thresholds used to estimate effects for a broad range of frequencies from multiple sonar types,

Program Insights

ensuring applicability to future naval sonar systems. Another completed project, Developing Tools for Acoustic-only Behavioral Response Studies at Navy Instrumented Ranges (page 36), developed automated tools to help analysts extract whale swim track kinematic data more efficiently from the Navy range hydrophone data. Demonstrating these tools allows the researchers to get one step closer to studying marine mammal behavioral response to sonar using passive acoustic monitoring alone. Being able to use passive acoustic data from Navy ranges to study behavioral response, particularly in challenging locations and for elusive species, will enable the Navy's monitoring program to collect response data more efficiently than other survey methods, such as visual focal follows and animal tagging.

Your participation and support keeps the program focused on priority needs and well-coordinated with other Navy efforts.

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

Results from all of these current and past projects continue to contribute to the scientific literature that provides critical, well-founded scientific information needed by the Navy's Fleet and Systems Command (SYSCOM) environmental planners, regulators, scientists and other stakeholders. Sixteen publications and technical reports, resulting directly from LMR-supported projects or using data from LMR projects, were produced in 2019 and several more will be released in 2020.

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

Anu Kumar
Program Manager

Mandy Shoemaker
Deputy Program Manager

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

Anu Kumar, Program Manager

Mandy Shoemaker, Deputy Program Manager

Program Overview

Mission

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

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

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

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

PROGRAM HISTORY

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

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

Efforts were broadened in 2000 to include a new focus on the effects of mid-frequency sonar on beaked whales—the species thought to be most sensitive to that sonar. Between 2000 and 2007, the Navy began work to identify what information would be needed to obtain regulatory agency approvals for its major at-sea training ranges. In 2007, the research efforts were refocused to fulfill these information needs.

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

With a significantly expanded knowledge base, the distinctions among basic research (6.1 and 6.2 programs), applied research and testing

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

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

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

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

NAVY READINESS DEPENDS ON ENVIRONMENTAL COMPLIANCE

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

As part of the regulatory compliance process associated with these Acts, the Navy is responsi-

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

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

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

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

NAVY PROGRAMS THAT ENABLE ENVIRONMENTAL COMPLIANCE

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

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

To promote ongoing coordination among the three programs, the program manager from ONR MMB and representatives from the MSM program are members of the LMRAC (described on page 11).

The Office of Naval Research Marine Mammals and Biology Program

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

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

The Living Marine Resources Program

The LMR program is structured to focus on outcomes for Navy end users and to address the needs of the Navy's at-sea environmental compliance community. As a 6.4 late stage applied research program, LMR develops, demonstrates, validates and assesses the data, methods and technology solutions needed to study protected living marine resources that may be affected by training and testing activities.

The LMR program serves a number of unique functions that the other two programs cannot provide.

These functions help to address priority, end-user focused needs at the applied research level:

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

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

U.S. Navy Marine Species Monitoring Program

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

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

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

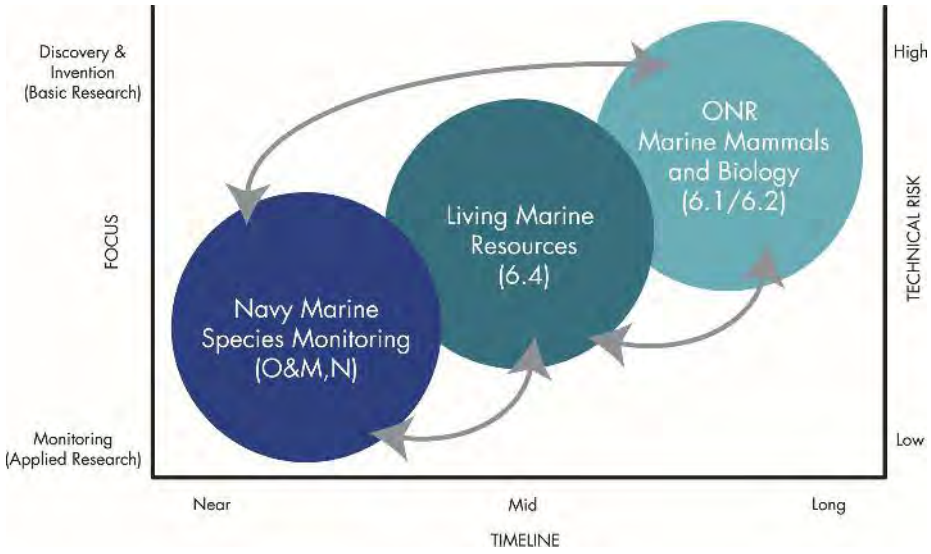
By providing a centralized program to address the Navy end users' stated needs, LMR provides a clear path for getting solutions and results to all who need them.

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

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

STRUCTURE

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



Advisory Committees

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

LMR Advisory Committee

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

- OPNAV N45
- Commander, U.S. Pacific Fleet (PACFLT)
- U.S. Fleet Forces (USFF)
- Naval Information Warfare Systems Command (NAVWAR)
- Naval Sea Systems Command (NAVSEA)
- Naval Air Systems Command (NAVAIR)
- Naval Facilities Engineering Command (NAVFAC)
- ONR.

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

Technical Review Committee

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

Program Office

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

Resource Sponsor

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

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. Four key factors that guide project selection are

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

Program Investment Areas

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

1. Data to support risk threshold criteria

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

LMRAC members provide critical Navy end user perspectives.

Approach: obtain and analyze data on how well animals can hear, how and when animals may be exposed to acoustic and explosive sources, and how animals respond or are affected when

Joel Diller

exposed. The data are used to develop risk threshold criteria, to inform the Navy's acoustic and explosive impact assessments and determine appropriate mitigation measures to reduce impacts to protected marine species. Projects in this area can include hearing studies, sound exposure and behavioral response studies.

2. Data processing and analysis tools

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

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

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

3. Monitoring technology demonstrations

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

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

4. Standards and metrics

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

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

5. Emergent topics

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

Humpback whale.
NOAA/NMFS

Navy Needs

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

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

Anyone within the Navy may submit needs for consideration by the LMR program. For details on submitting needs, see the program website at www.navfac.navy.mil/lmr. Non-Navy personnel can discuss need ideas with a Navy employee for consideration. The Navy employee can choose to sponsor and submit externally-generated needs as appropriate. Submitted needs are validated and ranked by the LMRAC, and then recommendations are made to the OPNAV N45 resource sponsor.

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

Priority Species and Geographic Regions

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

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

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

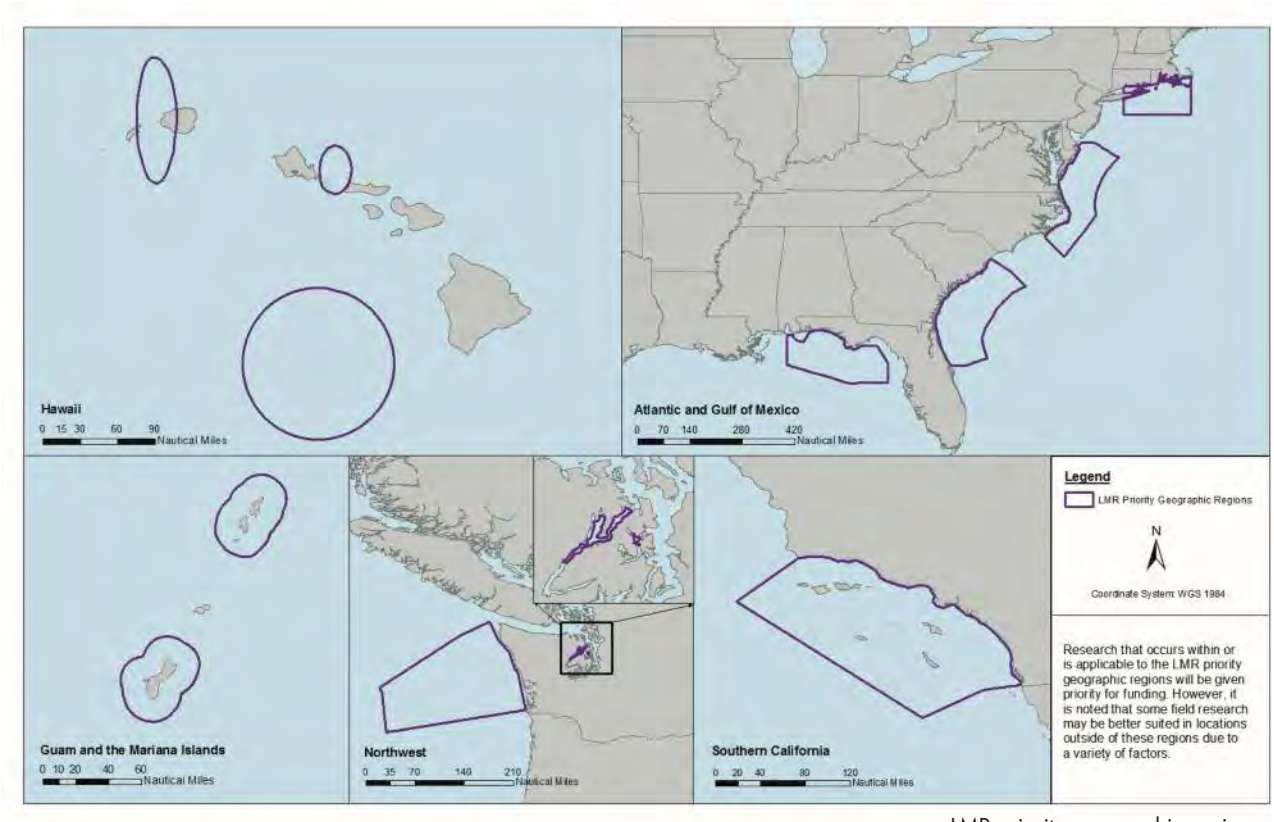
The LMR program is primarily interested in funding research that is applicable to geographic regions that are important to the U.S. Navy. The map below shows the LMR program priority geographic regions. It is important to note that the LMR program acknowledges that a variety of factors could lead to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

Coordination/Collaboration with Other Programs, Agencies and Research Institutions

The program makes a concerted effort to continually expand and strengthen our network of partners, which is the fourth line of effort described in the Navy's Design for Maintaining Maritime Superiority (Version 2.0). The program does this by

- Maintaining close alignment across the U.S. government, including partnerships with agencies such as National Oceanographic and Atmospheric Administration (NOAA), Marine Mammal Commission (MMC) and Bureau of Ocean and Energy Management (BOEM)
- Advancing the Navy's partnership with industry through Broad Agency Announcements (BAAs) and Small Business Innovative Research (SBIR) efforts
- Enhancing cooperation with academic and research institutions, shown by the program's projects being conducted by roughly 15 different academic and research institutions.

An example of multi-agency coordination is LMR's active participation on the Subcommittee on Ocean Science and Technology (SOST).



LMR priority geographic regions.

The SOST's purpose is to advise The National Science and Technology Council's Committee on the Environment, Natural Resources, and Sustainability (CENRS) on national issues of ocean science and technology and to serve as the lead interagency entity for federal coordination on those matters. One component of SOST is the Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML), formed to increase coordination and communication across federal agencies in addressing issues related to the potential impacts of anthropogenic noise on marine life. The SOST ITF-ONML issued a call for pre-proposals via the LMR program in July 2018 pertaining to development of audiograms for mysticetes. The LMR program is currently managing two of the three

SEEKING NEAR REAL-TIME MONITORING OF BALEEN WHALES

One LMR partnership project is demonstrating the benefits of cooperation to move an important technology from development to validation to application. The results will help to address Navy monitoring needs. The technology has advanced due to the support and efforts of the Office of Naval Research MMB program, university researchers, the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP), NAVFAC Atlantic, Naval Oceanographic Office (NAVOCEANO) and the National Oceanic and Atmospheric Administration (NOAA).

The project, "Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales," has been validating a system to detect and classify target species of baleen whales using autonomous vehicles. The enabling technology is a combined hardware/software system that uses a digital acoustic monitoring instrument (DMON) and low-frequency detection and classification system (LFDCS) to detect underwater sounds and automatically analyze the sounds to determine if they are from any of the four baleen whales of interest. The initial DMON/LFDCS package was developed by researchers at Woods Hole Oceanographic Institution (WHOI) with funding from the ONR MMB program.

Technology demonstration/validation was co-funded by LMR and DoD ESTCP and has benefitted from significant in-kind support. The demonstration project has been conducted by researchers from NAVFAC, WHOI and the NOAA Northeast Fisheries Science Center (NEFSC). The project began testing on three autonomous platforms—moored buoy, wave glider and Slocum glider. Deployed Slocum gliders included devices from both WHOI and from NAVOCEANO. Deployments and recovery were supported by NOAA ships *Gordon Gunter* and R/V *Tioga*, as well as vessels from the Northeast Consortium. Aerial survey support was provided by NEFSC and the New England Aquarium.

This level of cooperation and leveraged and in-kind funding enabled deployments on multiple platforms, protocols to ensure valid results, human analysts to validate detection and classification data and aerial surveys for visual verification. All of this effort significantly expanded the project capacity from its initial funding levels. In addition to the monitoring tools this can provide to the Navy, it is now being used by NOAA, Department of Fisheries and Oceans Canada and Transport Canada to incorporate near real-time passive acoustic monitoring into their North Atlantic right whale management program.

For more on this project, see the summary in the Completed Projects section (page 33).

projects chosen from the pre-proposals. These two projects, Collection of AEP Hearing Thresholds in Minke Whales, and Towards a Mysticete Audiogram Using Humpback Whales' Masked Behavioral Response Thresholds, are summarized on pages 59 and 61, respectively.

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

Another example of LMR's partnership efforts, which reflects valuable cross-agency efforts, is highlighted in the accompanying case study, Seeking Near Real-time Monitoring of Baleen Whales.

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

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

Cpl. Jacob A. Farbo

financial expectations, reporting requirements and ongoing communication with program staff. The goal is to establish a framework that promotes project success and keeps projects targeted on meeting Navy needs.

When a project approaches its completion and its results demonstrate that an approach can successfully meet the Navy need, the program works to move the demonstrated solutions out of research and into the hands of the appropriate Navy end users. While this stage represents the final step in the formal project process, the LMR program does continue to track a project's success and solicit feedback about the integration. Some of the conditions that define successful integration include

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

MANAGEMENT AND COMMUNICATION TOOLS

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

Quarterly Newsletters

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

Project Highlights Fact Sheets

Fact sheets highlighting key aspects of LMR-funded projects provide a quick view into

program investments. The fact sheets, available on the LMR website, provide a summary of the following topics for each project:

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

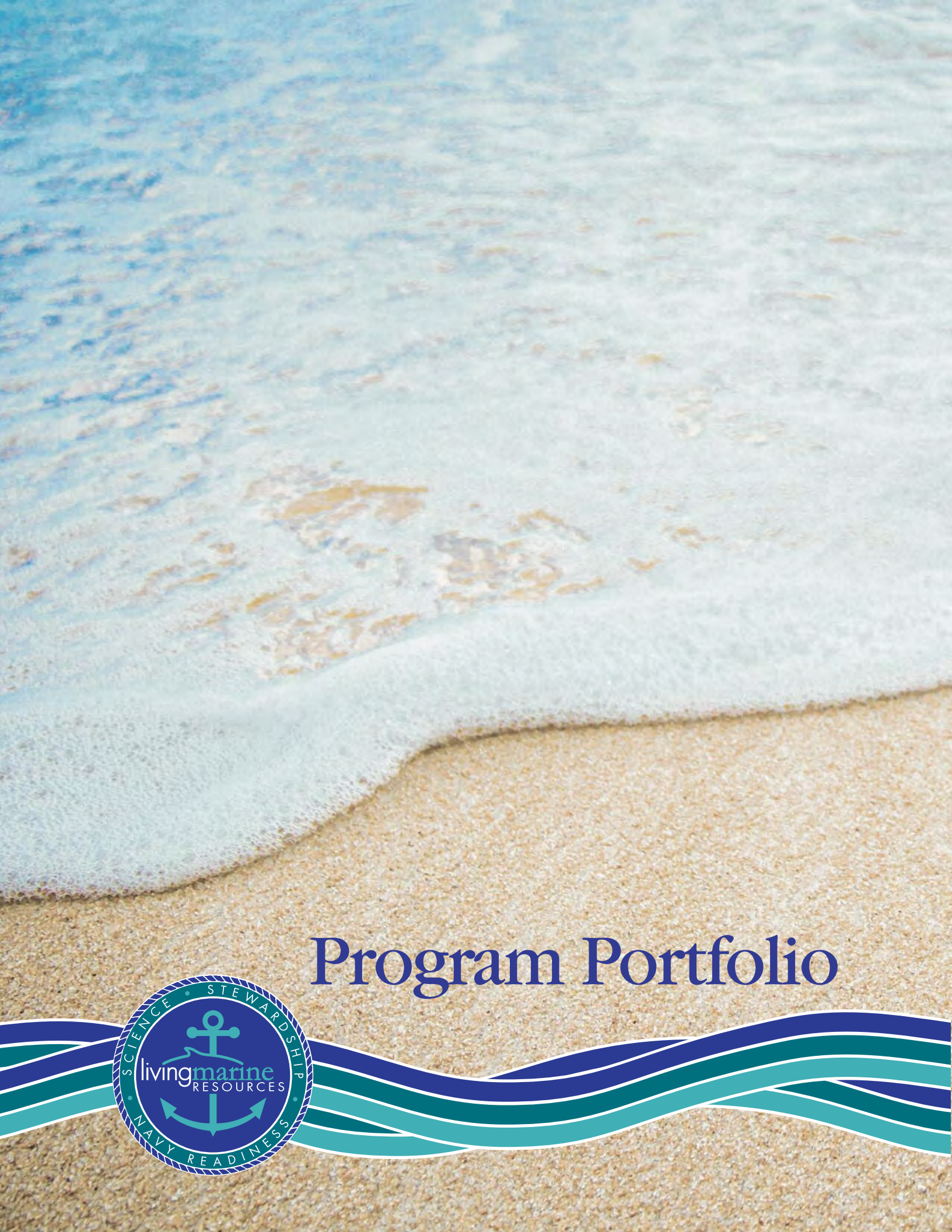
In-progress Review

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

Go to www.navfac.navy.mil/lmr for public information about the LMR program.

LMR Website

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



Program Portfolio

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Completed Projects

Seven projects were completed during 2019 and are summarized in this section. Five of the projects were LMR-funded and two were partnerships in which LMR worked with other organizations on funding and management. Results from these projects are now available for use by the Marine Species Monitoring program and those involved in environmental compliance.

The five completed LMR projects are

1. Project 6—Database and Metrics for Testing Automated Signal Processing for Passive Acoustic Monitoring
2. Project 10—The Effects of Noise on Marine Mammals: Progress Since 1995
3. Project 19—DECAF-TEA: Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas
4. Project 20—Behavioral Dose-Response Relationship and Temporary Threshold Shift in Harbor Porpoises
5. Project 25—A Blainville's Beaked Whale Behavioral Risk Function for Hawaiian Populations.

The two completed partnership projects are

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

LMR Projects

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

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

NEED

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

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

PROJECT

Processing extensive passive acoustic monitoring (PAM) data sets to detect and classify marine mammal calls has typically relied on manual analysis by trained acoustic data technicians.

This project ultimately examined the characteristics of four metrics for performance evaluation.

Because that manual approach is labor-intensive and results can vary depending on the analyst, automated data processing tools, called detectors and classifiers, could offer the Navy efficiency benefits. These continually evolving automated tools do need to be carefully evaluated, however, because each type analyzes data differently, making it difficult to compare results.

Risso's dolphins.
Wayne Hoggard, NOAA/NMFS

This project focused on developing measures for evaluating automated detectors and classifiers to help to evaluate their performance. The project entailed preparing common data sets of marine mammal calls to use when evaluating detectors and classifiers, and developing standard metrics by which to compare the performance of the detectors and classifiers. The team constructed marine mammal sound data sets specific to particular Navy training areas in the Pacific and Atlantic Oceans, then composed a standardized set of metrics against which the performance of both existing and potential new automated tools can be evaluated. Each data set is comprised of two components: 1) a training data set to fine tune the detector and classifier, and 2) a separate evaluation data set to test the performance. Each data set was manually annotated by experts to identify marine mammal calls that are considered ground truth. These data sets are available online at the Scripps Institute of Oceanography Whale Acoustics Laboratory site, www.cetus.ucsd.edu.

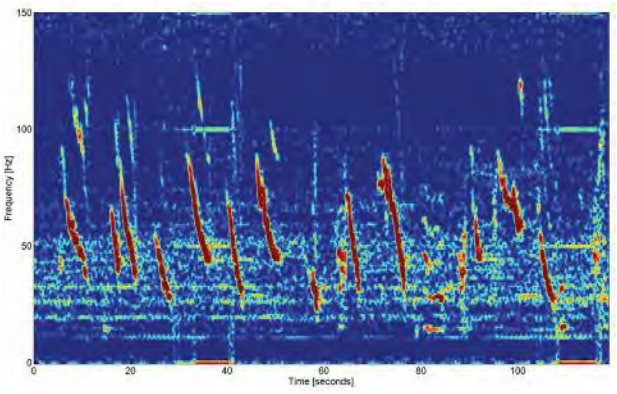
A Pacific data set that includes blue whale D-calls and multiple odontocete species calls was tested in 2015. A subsequent Atlantic data set was completed for ten known call types: Gervais' beaked whale, Cuvier's beaked whale, Sowerby's beaked whale, Risso's dolphin, Atlantic white-sided dolphin, short-finned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

This project worked with members of the marine mammal detection and classification community to develop a standardized set of metrics for evaluating the performance of automatic detector and classification outputs. A metrics committee, formed in 2015, sought to define universally appli-

cable measures for both existing and potential new automatic detection tools for specific baleen whale calls and odontocete signals.

This project ultimately examined the characteristics of four metrics for performance evaluation: receiver-operating-characteristic (ROC) curves, detection-error-tradeoff (DET) curves, cost curves, and precision-recall (PR) curves. As part of two case studies, the team applied the chosen performance metrics to the Generalized Power Law (GPL) detector for blue whale D calls (Helble et al. 2012) and the click-clustering neural-net algorithm for Cuvier's beaked whale echolocation click detection (Frasier et al. 2017) using the Pacific data set described in paragraph three above. This Pacific data set was used as the test data set for the 2015 Detection, Classification, Localization and Density Estimation Workshop.

These case studies demonstrated that there are clear trade-offs when deciding what metrics are appropriate for a specific detector. Three of the metrics (ROC, DET and cost) all require discrete time periods for assessment to be created. The grouping, or bin, chosen for these discrete periods (the discretization bin) affects the performance metric. Selecting short time bins results in a large number of true negative events (neither predicted nor actual call), which will inherently reduce the false-positive rate used in the ROC and DET metrics. Longer time bins may improve understanding of the detector performance but at the expense of temporal resolution. Longer time periods can obscure problems with the detector by aggregating periods with good and poor performance. Although various approaches have been proposed to account for class imbalance it is still a significant problem for signal classification. The fourth method, PR, showed a clear advantage because it does not require discrete time-binning of the data and therefore may be less subject to the issue of class imbalance described above.



Recorded blue whale "D" calls, often made during foraging activity.

These case studies demonstrated that there are clear trade-offs when deciding what metrics are appropriate for a specific detector.

The detailed results from the two case studies were delivered to the LMR program in the form of a final report. The LMR program is looking forward to this work leading to further discussions regarding the establishment of a standardized set of metrics for evaluating the performance of automatic detector and classification outputs.

About the Principal Investigator

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

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

The Effects of Noise on Marine Mammals: Progress Since 1995

Principal Investigators:
Christine Erbe, Dorian Houser
Project Status: Completed, Project 10

NEED

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

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

PROJECT

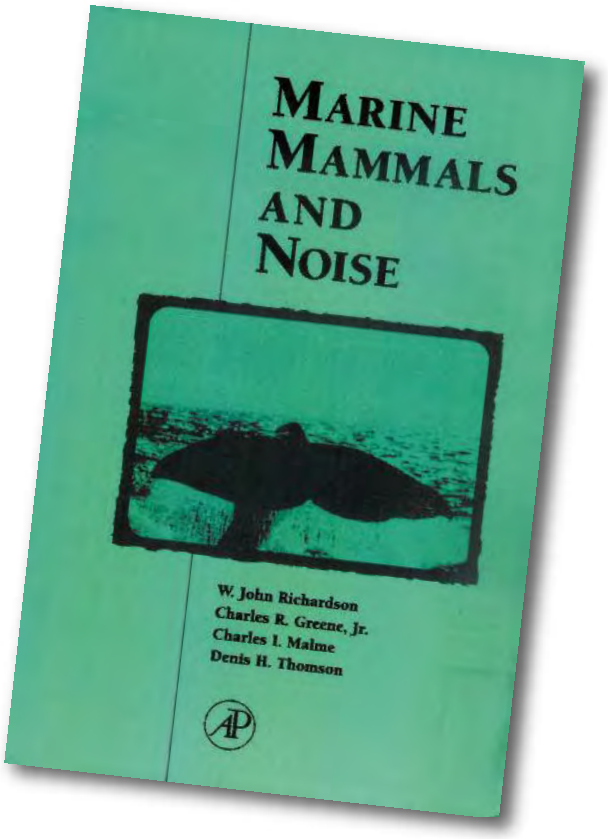
The book *Marine Mammals and Noise* (Richardson et al. 1995) has been the single most cited resource for information on the effects of noise on marine mammals since its publication. It has been a valuable resource for the Navy, environmental planners, regulators and scientists. However, in the last 20+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

This project has worked to gather, analyze and summarize all updated information available pertaining to the effects of noise on marine mammals. The information is being compiled as an updated source that marine resource specialists within the Navy can reference to develop at-sea environmental compliance documentation. This tool will help the Navy to strengthen its ocean science technical workforce.

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

1. Developing a database of literature on marine mammal bioacoustics
2. Developing a standardized database of studies conducted on marine mammal hearing
3. Analyzing and summarizing available data on the sounds produced by marine mammals and on marine mammal hearing
4. Analyzing available information and preparing a recommendation on how marine mammal bioacoustic data can inform both conservation efforts and the management of marine resources.

The databases described under Tasks 1 and 2 were completed and were used to inform preparation of three reports pertaining to Tasks 3 and 4.



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

The project team anticipates that a book presenting additional material, supported by other funders, will be published in 2020. The intent of the project team is that the content of the three reports submitted to LMR will lead to three separate chapters in the book (marine mammal sound production, marine mammal hearing and conservation and management of marine resources).

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

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

About the Principal Investigators

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

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

Humpback whales.

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

Principal Investigators:
Ron Morrissey, Len Thomas
Project Status: Completed, Project 19

NEED

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

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

PROJECT

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

The project included both statistical survey and hardware design components. Optimal acoustic recorder array spacing, needed to provide sufficient data for statistical analyses, was finalized in 2017. Major progress also was made on the hardware design and modification. Work during 2018 centered on field testing the passive acoustic sensor arrays. The system is based on an existing design fielded by the Underwater Tracking Range Equipment program called a Portable Acoustic Data Node (PADN). PADNs are designed and constructed at the Naval Undersea Warfare Center Newport. The DECAF-TEA sensor system is equipped with four hydrophones that form a tetrahedral array. The four hydrophones in the tetrahedral array provide signal bearing estimates necessary to the statistical density estimates.

> This project is an excellent example of why it is so important to have the LMRAC members and project PIs work closely together to continue to evaluate project progress.

A field test was completed in Narragansett Bay, Rhode Island. A second system field test was conducted on the Southern California Offshore Range (SCORE) during the summer of 2018. Following successful deployment and initial testing, problems arose during retrieval. The PADN systems were configured to release by an acoustic signal and float to the surface, however none of the three systems released as intended. Following retrieval by a remotely operated vehicle, the systems were analyzed to identify the release problem to ensure successful release in future efforts. The primary failure mode was a flawed power analysis that did not take into account modifica-

Cuvier's beaked whale.
Gregory S. Schorr, permit 16111

tions to the base PADN design to support the recording from the tetrahedral array.

During early 2019, several system components were redesigned to address many of the issues discovered after the 2018 testing. A subsequent deployment of the PADN system was planned for 2019 to test the redesigned hardware. Because of scheduling delays on the SCORE range, subsequent validation deployments could not be implemented. This provided an opportunity to step back and review if the technology being considered would be appropriate for end-users even if the validation deployments were technically successful.

The LMRAC members and project principal investigators (PI) reviewed the status of the PADN technology development, as well as proposed costs associated with using the PADN technology for future monitoring applications. Ultimately, it was determined that the technology was not mature enough to move forward with the project at this time. The PADN system, as currently configured, would not be able to record for the number of consecutive days required in the survey design. In addition, the team also realized that the level of effort and associated costs to deploy the number of PADN units needed to achieve the optimal array spacing needed for density estimation were too high for future monitoring applications. All agreed not to proceed further until the technology matured and costs could be reduced.

This project is an excellent example of why it is so important to have the LMRAC members and project PIs work closely together to continue to evaluate project progress. The LMR program funds applied research and sometimes investments are risky. This project made great strides in determining what areas need to be focused on first (technology and cost), before proceeding with these project goals in the future. This team made some excellent progress on this topic and the developments on the PADN system that have been made thus far will be useful to the overall Navy for training and testing purposes.

About the Principal Investigators

Ron Morrissey has been employed by the Naval Undersea Warfare Center in Newport, Rhode Island since 1995. He is the current Technical Direction Agent (TDA) for the Underwater Tracking Range Equipment program. He specializes in signal detection including detecting and classifying marine mammals and designing embedded systems for data collection and processing. Dr. Morrissey holds a Ph.D. in electrical engineering from Boston University.

Len Thomas is Professor of Statistics and member of the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. He specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in forestry from the University of British Columbia.

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

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

NEED

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

To understand whether sound from Navy activities is affecting marine mammals, it is necessary to understand more about their hearing. There is a need to understand how signal characteristics other than frequency may also affect the hearing, behavior, and physiology of marine mammals. The Navy needs improved hearing data in order to update risk threshold criteria, reduce the uncertainty of the current impact assessments and validate mitigation measures.

PROJECT

A variety of Navy sonar sources are audible to harbor porpoises (*Phocoena phocoena*), a small odontocete (toothed whale) species that has a wide distribution area in the Northern Hemisphere.

Results of the first two phases of the TTS study were published in *The Journal of the Acoustical Society of America*.

Because of limited available data on this species, predictions of temporary hearing threshold shift (TTS) or behavioral response previously have been derived from surrogate, mid-frequency cetacean species exposed to other sound sources (e.g., airguns). Therefore, these predictions of impacts might be inappropriate for harbor porpoises. Behavioral response and TTS data specific to harbor porpoises are needed to improve estimates of potential effects from exposures related to Navy training and testing activities on porpoise hearing and behavior.

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

The behavioral dose-response study's two phases were to

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

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

Phase two results were published in *Aquatic Mammals* in 2019. Results suggest that for the 53-C sonar signals at 96 percent duty cycle, the received signal to noise ratio needs to be lower than 54 dB re 1Hz for the background noise to have a masking effect. Therefore, sea state can influence the threshold of behavioral response.

The three TTS study phases were to

1. Establish the audiograms of the two study animals. Because the animals arrived at SEA-MARCO (Sea Mammal Research Company, Inc.) just before the start of the studies for LMR, their basic hearing thresholds needed to be established.
2. Study TTS in harbor porpoises from exposure to 53-C sonar playback sounds (3.5-4.1 kHz) at 96 percent duty cycle with exposure durations of 30 and 60 minutes. (Note that this approach was used because TTS could not be established with exposure to 53-C sonar playback sounds at a duty cycle of 2.7 percent at the highest sound pressure level that could be produced in the pool. This is due to the low acoustic energy per time unit and the fact that the ear could also recover during the long inter-pulse intervals (2.7 percent duty cycle means one 1.6 second sonar signal every 60 seconds).
3. Establish equal TTS curves for the entire harbor porpoise hearing range, incorporating data from the following frequencies: 0.5, 16, 32, 63 and 88.4 kHz.

Results of the first two phases of the TTS study were published in *The Journal of the Acoustical Society of America* during 2017. The first publication included audiograms for the two animals. The second publication included results of TTS phase two, which showed that the initial (1-4 min) 6 dB TTS measured at 4 kHz (96 percent duty cycle) required a sound exposure level that was as expected from previous harbor porpoise studies with sounds of adjacent frequencies (2 and 4 kHz).

All phase three data collection for TTS curves over the entire hearing range was completed and analyzed. Analyses for all planned frequencies were completed, and manuscripts on three frequency levels (16 kHz, 32 and 63 kHz) have

Porpoise Flow at transducer.
Lean Helder-Hoek

been published in *Aquatic Mammals*. The manuscript for the 88.4 kHz level is in review at *Aquatic Mammals*, while the 0.5 kHz manuscript is in preparation. The final two manuscripts on the remaining frequencies are to be published in 2020. The summary of the results suggests that harbor porpoise are less susceptible to TTS than predicted, across the entire hearing range.

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

The results of these behavioral dose-response and TTS studies are being used to update the underwater acoustic criteria and thresholds for harbor porpoises that are used to estimate potential exposures from Navy training and testing activities. Publications to date from these studies are listed below.

About the Principal Investigator

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

Project publications through 2019 (two more to be published in 2020)

Kastelein, R.A., Helder-Hoek, L. and Van de Voorde, S. (2017). Hearing thresholds of a male and a female harbor porpoise (*Phocoena phocoena*). *Journal of the Acoustical Society of America*, 142: 1006–1010. (DOI: 10.1121/1.4997907)

Kastelein, R.A., Helder-Hoek, L. and Van de Voorde, S. (2017). Effects of exposure to 53-C sonar playback sounds (3.5–4.1 kHz) on harbor porpoise (*Phocoena phocoena*) hearing. *Journal of the Acoustical Society of America*, 142: 1965–1975. (DOI: 10.1121/1.5005613)

Kastelein, R.A., Helder-Hoek, L., Van de Voorde, S., de Winter, S., Janssen, S., and Ainslie, M.A. (2018). Behavioral responses of harbor porpoises (*Phocoena phocoena*) to sonar playback sequences of sweeps and tones (3.5–4.1 kHz). *Aquatic Mammals*, 44(4): 389–404. (DOI 10.1578/AM.44.4.2018.389)

Kastelein, R.A., Ainslie, M.A., and van Kester, R. (2019). Behavioral responses of harbor porpoises (*Phocoena phocoena*) to U.S. Navy 53C sonar signals in noise. *Aquatic Mammals*, 45(4): 359–366. (DOI: 10.1578/AM.45.4.2019.359)

Kastelein, R.A., Helder-Hoek, L., van Kester, R., Huisman, R., and Gransier, R. (2019). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth-octave noise band at 16 kHz. *Aquatic Mammals*, 45(3): 280–292. (DOI: 10.1578/AM.45.3.2019.280)

Kastelein, R.A., Helder-Hoek, L., Cornelisse, S., Huijser, L.A.E., and Gransier, R. (2019). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth-octave noise band at 32 kHz. *Aquatic Mammals*, 45(5): 549–562. (DOI: 10.1578/AM.45.5.2019.549)

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

Principal Investigators:
Len Thomas, Elizabeth Henderson
Project Status: Completed, Project 25

NEED

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

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

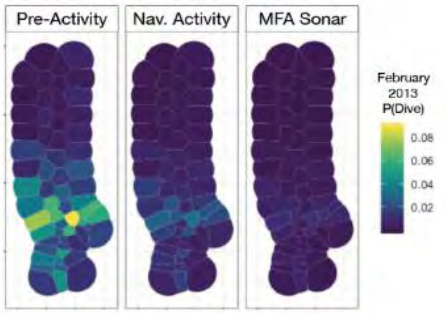
PROJECT

The Navy conducts acoustic impact assessments as part of the environmental regulatory framework for at-sea training and testing area permits. These assessments incorporate behavioral risk functions developed for groups of marine mammals, one of which is beaked whales. The behavioral risk function currently in use for beaked whales by the Navy incorporated data from a risk function developed for Blainville's beaked whales (*Mesoplodon densirostris*) found at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas.

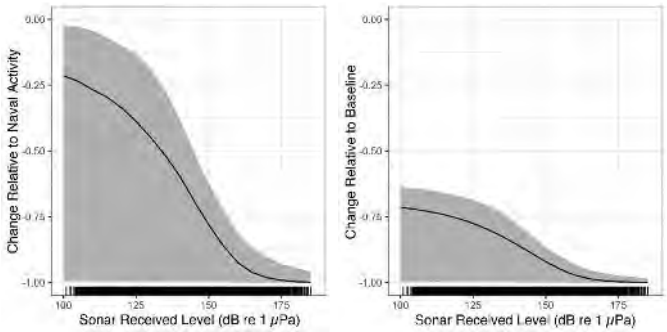
The primary goal of this project was to develop and publish the first behavioral risk function for Blainville's beaked whales found on the Pacific Missile Range Facility (PMRF) undersea hydrophone range in Hawaii. It was designed to provide a direct comparison of risk functions derived for the same species, exposed to the same acoustic source types, in different ocean basins.

The project adapted the methods used at AUTEC to animal detections at PMRF and demonstrated how the methodology can be extended for use in different locations. A number of differences between the AUTEC and PMRF undersea hydrophone ranges required adjustments to the model used to develop behavioral risk functions for Blainville's beaked whales at AUTEC. Differences include lower animal densities, more variable hydrophone spacing at PMRF and significantly different seafloor substrate and contours, which affect sound propagation.

The project team first applied the AUTEC model to available acoustic data collected on the PMRF



Expected probability of acoustically detecting groups of Blainville's beaked whales (color scale) before (left panel), during training activity (middle panel) and during hull-mounted MFA sonar (right panel) at PMRF range hydrophones in February 2013.



Expected change (black line) in the probability of acoustically detecting Blainville's beaked whales (y-axis) with increasing received levels of hull-mounted MFA sonar (x-axis) as compared to periods when Naval training activity is present (left panel) and as compared to a pre-activity baseline period (right panel). Gray shading indicates 95% CIs.

hydrophones to identify additional data needs and model modifications. The data used were from a previously conducted Submarine Command Course (SCC) training event. Those data were used to identify presence of Blainville's beaked whale group vocalization signals and sonar signals and to estimate received levels per group.

This will provide Navy environmental compliance analysts with data to update the next-generation Navy Behavioral Response Criterion for beaked whales.

Building from the initial effort, the team expanded the data set to include multiple SCC events and modified the model to include three sub-models. One is a baseline spatial model (M1), which used data collected prior to the SCCs, to account for uneven hydrophone spacing, to address variability of data available from different hydrophones and different SCCs and to incorporate the underlying distribution of Blainville's beaked whales. Because initial analyses indicated that vocalizations appeared to decrease at the onset of training activity, prior to the use of hull-mounted mid-frequency active sonar, a second model for training activity (M2) was developed to separate the expected decrease in vocalizations due to training activity from the expected decrease due to MFA sonar. This model used the output of M1 to account for variability in hydrophone data and beaked whale distribution. The third model (M3) describes the probability of detecting groups of animals as a function of sonar received level (RL), with an offset for the initial decrease found due to training activity (M2).

These three models are used to calculate the expected percentage change in probability of detecting a group of whales between the baseline period (M1) and training activity (M2) and between the baseline period (M1) and different levels of sonar RL (M3).

Methods and results were presented at the World Marine Mammal Conference in Barcelona, Spain in December 2019, and will also be available through a peer-reviewed publication in 2020.

The resulting empirical dose-response function for SCCs at PMRF is based on real Navy sonar source data over a broad scale and includes a large number (more than 100) of beaked whale dive starts from multiple groups, offering insight into levels at which these animals react in the Hawaii environment. This will provide Navy environmental compliance analysts with data to update the next-generation Navy Behavioral Response Criterion for beaked whales.

About the Principal Investigators

Len Thomas is Professor of Statistics and member of the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. He specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in forestry from the University of British Columbia.

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

Partnership Projects

Autonomous Real-time Passive Acoustic Monitoring of Baleen Whales

Principal Investigators:
Cara Hotchkin, Mark Baumgartner
Project Status: Completed, Partnership

NEED

Demonstration of Technology to Monitor Marine Mammals

The Navy needs to be able to monitor sites of interest such as Navy training and testing areas. Passive acoustic monitoring (PAM) is a proven means of detecting, classifying and localizing vocally active marine mammals.

PROJECT

This project, a collaboration between the LMR program and the Department of Defense Environmental Security Technology Certification Program (ESTCP), has been working to validate technologies that can provide near real-time data of marine mammal occurrence. This technology could increase the efficiency of Navy monitoring efforts.

The overall objectives of this project included

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

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

The results of data analyses conducted during 2018 and early 2019 indicate significant benefits of the near real-time feedback from the Slocum glider deployments and moored buoys.

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

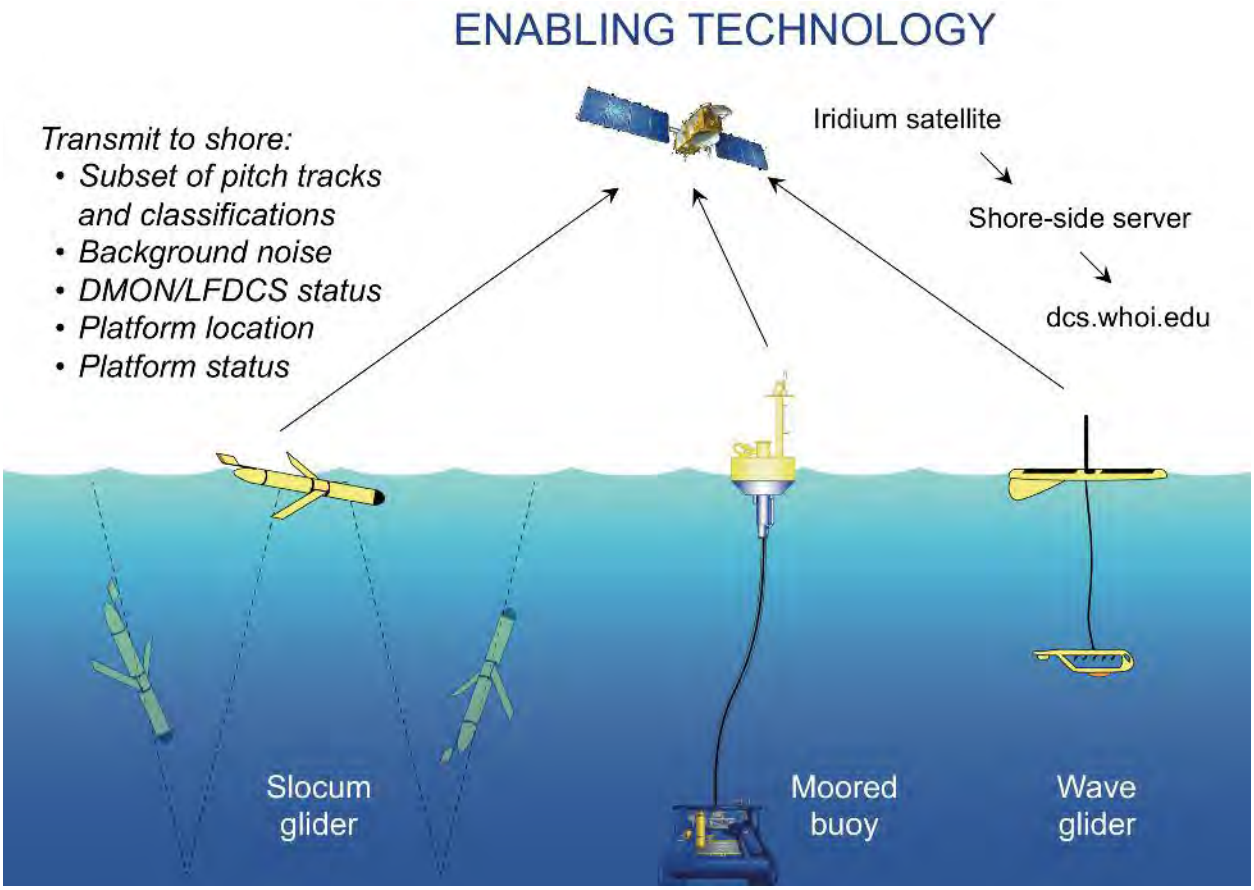
The moored buoy platform that was deployed between March 2015 and March 2016 suffered electrical issues, vandalism and noise. The buoy configuration was adjusted and redeployed between September 2016 and October 2017. The acoustic data from these deployments were compared to visual data collected during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

missed by both methods. Fin whales and male humpback whales may be easier to detect using acoustic methods than aerial surveys.

The Slocum glider was deployed multiple times in 2015 and 2016, including a coordinated deployment in Great South Channel off of Massachusetts that included both a Naval Oceanographic Office (NAVOCEANO) Slocum glider and the Woods Hole Oceanographic Institution (WHOI) glider. This successful one-month deployment demonstrated the use of the DMON/LFDCS package on a Navy asset and was a first step at transitioning the system to the Navy's Marine Species Monitoring Program. Related to that effort, NAVFAC Atlantic staff was trained on the deployment, recovery and analysis of the data. An independent mirror data analysis of the NAVOCEANO glider data by both Navy and Northeast Fisheries Science Center staff provided highly consistent results for all four species. An additional WHOI Slocum glider deployment was conducted in the Gulf of Mexico during 2017 to demonstrate detection capabilities for Navy stakeholders.

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

The results of data analyses conducted during 2018 and early 2019 indicate significant benefits of the near real-time feedback from the Slocum glider deployments and moored buoys. False and missed detections of the four baleen whale species were low or nearly nonexistent. One indication of the benefits is that these DMON/LFDCS systems are currently the only systems that meet



the criteria for providing near real-time right whale passive acoustic detections as outlined by the Northeast Implementation Team for Right Whale Recovery group. This ESA-mandated group, which includes a Navy representative, advises NOAA on right whale recovery activities.

Results of the moored buoy system were published during 2019 in *Methods in Ecology and Evolution*. Results of the glider deployments and human analyst efforts will be published in *Frontiers in Marine Science* in early 2020.

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

Principal Investigators

Cara Hotchkin
Naval Facilities Engineering Command Atlantic

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

Principal Investigators:
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Project Status: Completed, Partnership

NEED

Demonstration of Technology to Monitor Marine Mammals

The Navy needs information about how protected marine species respond to sound exposures in order to meet permit requirements for at-sea training and testing.

PROJECT

This project was part of a partnership among LMR, ONR MMB and Commander, Pacific Fleet (COMPACFLT) to develop and evaluate new software tools for efficiently conducting and reporting acoustic behavioral response studies on Navy instrumented ranges.

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

The Naval Information Warfare Center (NIWC), formerly the Space and Warfare Systems Center Pacific) has been collecting data from hydrophone arrays on the Pacific Missile Range Facility (PMRF) to acoustically monitor marine mammal activity since 2003. Such long-term monitoring has created robust acoustic data sets, both in the types and quantity of data. In addition, relatively recent improvements in localization software have allowed NIWC to acoustically detect, localize and track—with varying fidelity—several species of whales including beaked, humpback, minke, Bryde's, fin, sei, blue and sperm whales.

The tools developed under LMR funding support an ONR MMB effort, titled "Behavioral Response Evaluations Employing Robust Baselines and Actual Navy Training (BREVE)," and will ultimately support Pacific Fleet monitoring reporting required as part of permits.

The project team developed three software tools to help analyze metrics needed for acoustic behavioral response studies. Each tool and the associated work completed thus far is summarized below.

Tool 1: Interface for acoustic modeling software

This tool automatically estimates sonar sound pressure levels (SPL) and sound exposure levels (SEL) to tracked animals.

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

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

As a single species test, the team applied the tools to minke whale monitoring data. Animal source levels were estimated by adding transmission loss estimates to measured received levels of 42,159 individual minke whale boings. The results indicate a Lombard effect (the animal source level increases

Bryde's whale.
Wayne Hoggard, NOAA/NMFS

with increasing ambient noise). A manuscript presenting this effort is to be published in *The Journal of the Acoustical Society of America* in January 2020.

Tool 2:Automated track kinematics software

This tool groups whale localizations into tracks and automatically extracts relevant swim kinematics (e.g., animal's speed, direction, depth, etc.).

At project's start the process of assigning tracks and extracting kinematics required a higher degree of operator judgment, which could bias the results. This tool built on existing tracking software (multi-hypothesis tracking) and behavioral change-point software and added custom software as needed.

The methods were adapted from Naval Undersea Warfare Center's Multi-Hypothesis Tracker (MHT) and were successfully applied to both minke whale and humpback whale tracks. The output from the MHT provides the input to additional custom software that automatically measures whale kinematics.

Several kinematics software updates completed during 2018 provided more accurate estimates of instantaneous whale headings. These data products were subsequently applied to hundreds of minke whale tracks and were reviewed by the St Andrews BREVE statistical team to look for differences before, during and after Navy sonar exercises. Results of the ONR-funded portion were presented in an article, "Changes in the Spatial Distribution of Acoustically Derived Minke Whale (*Balaenoptera acutorostrata*) Tracks in Response to Navy Training," in the November 2019 issue of *Aquatic Mammals*.

In the final year, track kinematic software was further refined in coordination with the University of St Andrews to include the animal movement

model Crawl. This model allows a fusion of techniques to best estimate the true movement of the animal. This work was presented by Ian Durbach at the Society for Marine Mammal Mammalogy (SMM) conference in Barcelona, titled "Accounting for Localization Errors in Models of Behavioural Responses of Minke Whales to Sonar Activity During Navy Training." Several additional publications are expected from the BREVE project in which the kinematic software is utilized.

These automated acoustic efforts to detect, track, classify and measure detailed whale movement on the Navy's ranges have unlocked an abundance of detailed animal behavioral information previously not achievable with standard acoustic deployments.

Tool 3:Automated classifier for track information

This tool helps to process the thousands of tracks contained in archived data sets and is being applied to new data.

This effort began by using available classifiers, with modifications as needed to work on the PMRF and the Southern California Offshore ranges. Initial results were presented at the 2018 Detection, Classification, Localization and Density Estimation Workshop in June. Subsequent results were presented at the 2019 Aquatic Noise Conference, Den Haag.

Subsequently completed work has included context-based classification (adding additional classification by looking at groups of calls that are likely emitted by the same animal). Minke, humpback, sperm, Bryde's, fin, sei and blue whales can now be classified automatically, with the caveat that some fin and sei non-song bouts are not distinguishable (combined visual/acoustic surveys may be needed to fully separate the two types, if at all possible).

These three tools are already being used by projects funded by the Navy monitoring program, LMR and ONR. Two ongoing projects at NIWC include the COMPACFLT funded effort PMRF Data Collection and Analysis Acoustic Cues Project, which includes measuring the acoustic cue rate of over 1,000 automatically classified whale tracks on the PMRF range, spanning nearly a decade. The tools are also heavily used for the ONR MMB-funded Environmentally-influenced Behavioral Response EValuations (E-BREVE) project, which aims to quantify whale behavioral responses to naturally occurring events. These tools have also transitioned to other programs outside of NIWC, including another ONR MMB-funded project Using Context to Improve Marine Mammal Classification at San Diego State.

The automation developed under this effort allows scientists to complete analysis of large data sets in a fraction of the time, dramatically improving efficiency and standardizing the process. These automated acoustic efforts to detect, track, classify and measure detailed whale movement on the Navy's ranges have unlocked an abundance of detailed animal behavioral information previously not achievable with standard acoustic deployments. The data that can be extracted using these tools inform analysis of impacts from Navy sound sources and offer the potential to inform development of criteria and thresholds for behavioral response.

Principal Investigators

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Ongoing and New Start Projects by Investment Area

INVESTMENT AREA 1
DATA TO SUPPORT RISK THRESHOLD CRITERIA

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

Projects in this area can include hearing studies, sound exposure and behavioral response studies. Researchers collect and analyze data pertaining to animal hearing, potential exposure of animals to acoustic and explosive sources and how the animals respond or are affected. These data support risk threshold criteria and inform the Navy's acoustic and explosive impact assessments. Risk threshold criteria are values that estimate the likelihood that certain types of specified effects will occur. These criteria are also used to estimate the distance from sound source to animal response to help determine appropriate measures to reduce impacts to protected marine species. Improving the accuracy of such estimates will reduce overly burdensome mitigation requirements that can reduce training and testing realism.

The following section includes summaries of 12 projects, eight ongoing projects and four new projects started in 2019. Two of the new projects are part of LMR's work with the Subcommittee on Ocean Science and Technology (SOST) Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML).

The eight ongoing projects are

1. Project 22—Hearing and Estimated Acoustic Impacts in Three Species of Auk: Implications for the Marbled Murrelet
2. Project 23—Cuvier's Beaked Whale and Fin Whale Behavior During Military Sonar Operations: Using Medium-term Tag Technology to Develop Empirical Risk Functions
3. Project 24—Frequency-dependent Growth and Recovery of TTS in Bottlenose Dolphins
4. Project 26—The Effects of Underwater Explosions on Fish
5. Project 29—3S3: Behavioral Responses of Cetaceans to Naval Sonar
6. Project 30—Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar
7. Project 32—Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals
8. Project 33—TTS in Harbor Seals Due to Fatiguing Noise of Several Frequencies.

The four new start projects are

1. Project 37—Collection of AEP Hearing Thresholds in Minke Whales (SOST)
2. Project 38—Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds (SOST)
3. Project 39—Use of "Chirp" Stimuli for Non-invasive, Low-frequency Measurement of Marine Mammal Auditory Evoked Potentials
4. Project 40—Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles.

Ongoing Projects

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

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

NEED

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

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

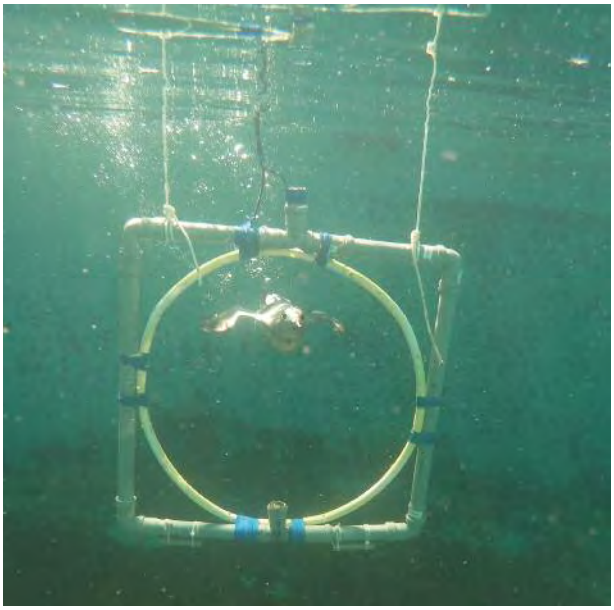
PROJECT

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

This project is defining the hearing of up to three Auk species—related to but not including the marbled murrelet—to provide data needed to predict the marbled murrelet's hearing. Over the course of the project, researchers are conducting both auditory evoked potential (AEP) methods and behavioral audiometric methods. Data collection efforts include in-air AEP tests, in-air behavioral audiometry tests and underwater behavioral audiometry tests. These tests will allow researchers to compare AEP and behavioral audiometric methods and to compare in-air and underwater measurements. The resulting audiograms will provide the data and training foundation for a TTS response feasibility study. In addition to AEP and behavioral audiometry testing, the team also is conducting computed tomography (CT) scans to define anatomical differences and similarities among the species.

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

Following an initial 2017 field effort focused on collection of in-air AEP data with a puffin and common murre, the team collected full in-air AEP audiograms on 10 puffins in 2018. In 2019, the project was expanded to include the addition of field-collected in-air AEPs on common murres in northwestern Iceland and marbled murrelets in Alaska, which are planned for 2020. During 2018 and 2019, the team also continued in-air behavioral hearing trials with a common murre. Several frequencies have been completed and the team is working to improve false detection rates.



The murre "Green" swimming through an underwater hoop for the underwater audiogram tests. Sensors at top and bottom of the hoop trigger start of trial.
Kirstin Anderson Hansen

The team is also working toward collecting underwater behavioral hearing data. For the first set of underwater trials in 2018, two common murres were trained to swim to a feeder at the bottom of the tank, sounds were played to the naïve birds, and responses were measured. The goal was to test if these birds heard underwater at all. In 2019, one of the common murres was trained for a more controlled test, to swim through an underwater hoop, triggering a sound. The bird then swam to the appropriate target based on whether or not it detected the sound. Following the underwater behavioral hearing test training conducted during 2018 and 2019, testing trials are planned for 2020. This work also is providing an initial foundation to determine whether TTS studies are feasible in the future.

Data analyses and manuscript preparation also proceeded during 2019. Two publications from 2019 included one detailing methods for collecting AEPs in the field, published in *Journal of Experimental Biology* (February 2019), and another on potential noise impacts on puffins was published in *Proceedings of Meetings on Acoustics* (September 2019). A third, on initial behaviors and hearing underwater of common murres, was submitted to *The Journal of the Acoustical Society of America*.

As of late 2019 researchers had completed 39 anatomical scans (15 in 2018, 24 in 2019). The highest quality samples were from Atlantic puffins (*Fratercula arctica*), for which the team has conducted sound exposure modeling on the reconstructed hearing structures. Using models that include a simulated sound source, the team can estimate pressure distribution across the ear canal at different frequencies to predict the most sensitive frequency. This can then be tested in puffins and ultimately applied to marbled murrelet anatomical scans. The team is continuing to analyze results and is also working to obtain high-quality murrelet samples.

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

About the Principal Investigator

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

Key collaborators: Marianne Rasmussen, University of Iceland; Magnus Wahlberg, University of Southern Denmark.

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

Principal Investigators:
Greg Schorr, Erin Falcone
Project status: Ongoing, Project 23

NEED

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

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

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

PROJECT

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

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

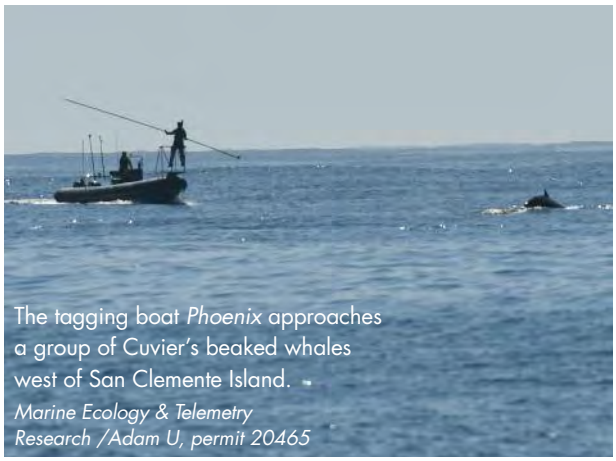
This project is closely coordinated with another LMR-funded project, Measuring the Effect of Range on the Behavioral Response of Marine Mammals Through the Use of Navy Sonar (Project 30). That project focuses on coordinated sonar exposure experiments.

Field efforts in Southern California began in 2017, where the team tagged a fin whale that was then subsequently exposed to helicopter dipping sonar. During 2018, the project team completed five field efforts successfully deploying three integrated, medium-term archival tags on Cuvier's beaked whales. The tags successfully collected data of both opportunistic and coordinated exposure. The team also began initial data analyses to combine animal movements and diving behavior from tags, tracks from ships and helicopters participating in exercises, and archived acoustic data from the range hydrophones and/or acoustic recording tags in a unified framework.

Field tagging efforts and data analyses continued during 2019. Lander2 tags were deployed on one Cuvier's beaked whale and one fin whale. In addition, five sound and motion recording and telemetry (SMRT) tags were deployed on Cuvier's beaked whales. The SMRT tags record acoustics, depth, speed and GPS location, data that significantly help when analyzing fine-scale behavior of the animal. In total, 71 days of high-resolution dive data have been collected from tagged Cuvier's, including approximately 20 days of acoustic data. Seven of the tagged whales are known to have been exposed to operational Navy sonar, including both ship and helicopter sonar in a variety of behavior states.

The team also work worked with Naval Postgraduate School analysts to model animal movement and sonar received level estimates from the 2018 tag data. An added data analysis effort during 2019 has focused on movement and accelerometry data from the Lander tags deployed in 2017 and 2018 to evaluate the potential to identify foraging dives when acoustic data are not available.

Additional tag deployments and data analyses are planned for 2020 and 2021. The priority species will be Cuvier's beaked whales, although fin whales also will be tagged when weather conditions do not support beaked whale tagging.



The tagging boat *Phoenix* approaches a group of Cuvier's beaked whales west of San Clemente Island.
Marine Ecology & Telemetry Research /Adam U, permit 20465

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

About the Principal Investigators

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

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

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

Frequency-dependent Growth and Recovery of TTS in Bottlenose Dolphins

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

NEED

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

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

PROJECT

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

The existing thresholds for assessing TTS and PTS in bottlenose dolphins were based on measurements from only a few individuals. These measurements were taken at selected frequencies thought to represent the range of the animal's best hearing, or the frequencies at which a sound source would be most likely to affect the animal. However, because recent research done with harbor porpoises has demonstrated that TTS susceptibility varies by frequency, information is needed on the entire frequency range. Additionally, the largest effects to hearing often occurred a half octave above the center exposure frequency. Therefore, this project attempts to investigate this in bottlenose dolphins.

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

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

Early project efforts focused on animal training, baseline hearing measurements and refining the TTS exposure protocols for this study. These were followed in 2018 by beginning high-frequency TTS data collection, including testing with 80-kHz fatiguing noise with a single dolphin. That testing


Bottlenose dolphin.

included 54 control sessions and 21 one-hour exposure sessions at exposure levels of approximately 139 to 165 dB sound pressure level (SPL), equivalent to approximately 175 to 201 dB sound exposure level (SEL). The project team also initiated TTS testing with 40-kHz fatiguing noise during 2018.

During 2019, the project completed behavioral and AEP threshold testing at 20, 40 and 80 kHz. Low-frequency testing at 0.5, 2, and 8 kHz was initiated but will be the focus of efforts in 2020.

Two manuscripts discussing auditory brainstem response in these dolphins were published in *The Journal of the Acoustical Society of America* in 2019. Citations are listed in the LMR Publications section at the end of this report.

Work during 2020 will focus on completing the low- and mid-frequency TTS testing, characterizing post-testing hearing (recovery), completing data analyses and preparing manuscripts for peer review.

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

About the Principal Investigator

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

The Effects of Underwater Explosions on Fish

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

NEED

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

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

PROJECT

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

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

The project team is studying explosive effects on fish species with differing characteristics (e.g., swim bladder morphology) and size, at varied water depths and distances from the source. Tissues from exposed fish (as well as from an extensive set of control samples) are examined using well-established necropsy techniques. Careful attention has been focused on ensuring a statistically valid experimental design. This approach

Deploying fish cage for testing.
Keith Jenkins


Mackerel.

will provide a broader and more comprehensive understanding of potential effects and dose-response relationships.

The Phase I trials completed in 2018 used Pacific sardines, held in cages deployed at 10 meters depth at multiple distances from the explosive source. Results from those trials were presented at the 2019 Aquatic Noise Conference and will be published in early 2020 in *The Journal of the Acoustical Society of America*.

Phase II trials were conducted during September 2019 following protocols and experimental design informed by the 2018 study. The target fish for these trials were Pacific mackerel (*Scomber japonicas*), representing a slightly larger species and different morphology. Drawing upon Phase I results, necropsy and ear tissue preservation techniques were modified to help to refine Phase II results. These data are now being analyzed.

Work during 2020 will include completing analyses of 2019 data and preparing for and conducting a third round of trials.

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

About the Principal Investigators

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

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

Key collaborator: Art Popper, University of Maryland.

3S3: Behavioral Responses of Cetaceans to Naval Sonar

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

NEED

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

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

PROJECT

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

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

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

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

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

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

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

The project has employed controlled (sonar) exposure experiments (CEE) using operational sonar sources from a research vessel and from a

Royal Norwegian Navy frigate KNM *Otto Sverdrup* (Nansen class) in early morning light. The towed operational sonar is visible at the aft of the frigate.
CDR René Dekeling (RNLN)

Norwegian frigate. The research team uses visual observers and acoustic arrays to locate whales of interest. When animals are located, a digital acoustic monitoring tag (DTAG)—in this case DTAG-3 or a mixed-DTAG—is attached by non-invasive suction cups to each animal that can be approached. The sensor package of the mixed-DTAG adds a GPS logger and satellite transmitter to the DTAG-3 sensor package. The tags are programmed to release after 15–17 hours.

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

During the 2016 and 2017 field season, the team successfully deployed DTAG-3s or mixed-DTAGs on 16 sperm whales and four pilot whales to record vocal, movement and dive behavior. The tags captured 236 hours of sperm whale behavioral data. Twelve full series of sonar CEEs (2 complete cycles of 6) were conducted with a scaled (but still realistic) sonar source. Baseline data also were collected from pilot whales.

During 2018, the team focused on analyzing data collected during 2016/2017 field seasons and on further testing of the mixed-DTAGs. A manuscript discussing results from these data collections has been accepted for publication in *Journal of Experimental Biology* and is scheduled to be issued in spring 2020.

The 2019 field work, conducted from mid-August to mid-September, included CEEs using both the previously used prototype (simulated) source (Socrates) from the research vessel HU *Sverdrup II* and an operational source (Captas) from the Norwegian Navy frigate KNM *Otto Sverdrup*. The team successfully tagged sperm whales with mixed-DTAG (recording sound, movement, location and diving depth) and conducted CEEs using pulsed active sonar (PAS) at different levels and ranges using the operational source on the Norwegian Navy frigate. Using the simulated source, the team completed additional CEEs mimicking the operational source transmission scheme. Overall the team deployed 24 tags and conducted 11 CEEs. Data analyses are now underway.

Sperm whale fluke as the whale begins one of its many deep dives.
Jacqueline Bort Thornton

A technical data report will be completed in 2020, as will manuscripts for peer-review publication.

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

About the Principal Investigators

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

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

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

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

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

NEED

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

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

PROJECT

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

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

The CSEE project includes both exposure and control scenarios for each of two types of sonar platforms—helicopter-dipping sonar and directional command activated sonobuoy system


MC3 Walter M. Wayman

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

(DICASS) sonobuoys. These were selected based on how frequently they are used during training on the Southern California Antisubmarine Warfare Range. Each sonar type is being tested as outlined in the table above. Standard mitigation actions are conducted prior to all experiments, as outlined in the research permits.

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

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

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

In 2019, in coordination with the successful SMRT tag deployments discussed under Project 23 (page 42), the teams completed three CSEEs with helicopter dipping sonar on Cuvier's beaked whales, filling in missing exposure distances collected from the opportunistic approach taken in project 23. Additionally, one control CSEE was conducted on a tagged fin whale. Data analysis efforts included reviewing M3R archive files for the presence of sonar during the tagging periods of 2017-2019. The team also began a comparison of received level modeling, using multiple models, to assess variance between modeling approaches and compare that with received levels from the acoustic tags. The coordination with the dipping helicopters in these cases provides for a precise source location and depth, which combined with the Fastloc GPS locations from the tagged whale makes this an ideal data set for which to conduct this test.

Additional CSEEs are planned during 2020 in coordination with tag deployment field efforts, depending on helicopter availability.

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

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

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

About the Principal Investigator

Stephanie Watwood manages the Marine Mammal Monitoring on Navy Ranges (M3R) Program in the Ranges, Engineering and Analysis Department at the Naval Undersea Warfare Center (NUWC). She has extensive experience in collecting and analyzing cetacean acoustic data, particularly related to cetacean behavior. Dr. Watwood holds a Ph.D. in biological oceanography from the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology joint program.

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

Cuvier's beaked whale.
Erin A. Falcone, permit 16111

Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

Principal Investigator: Colleen Reichmuth
Project Status: Ongoing, Project 32

NEED

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

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

PROJECT

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

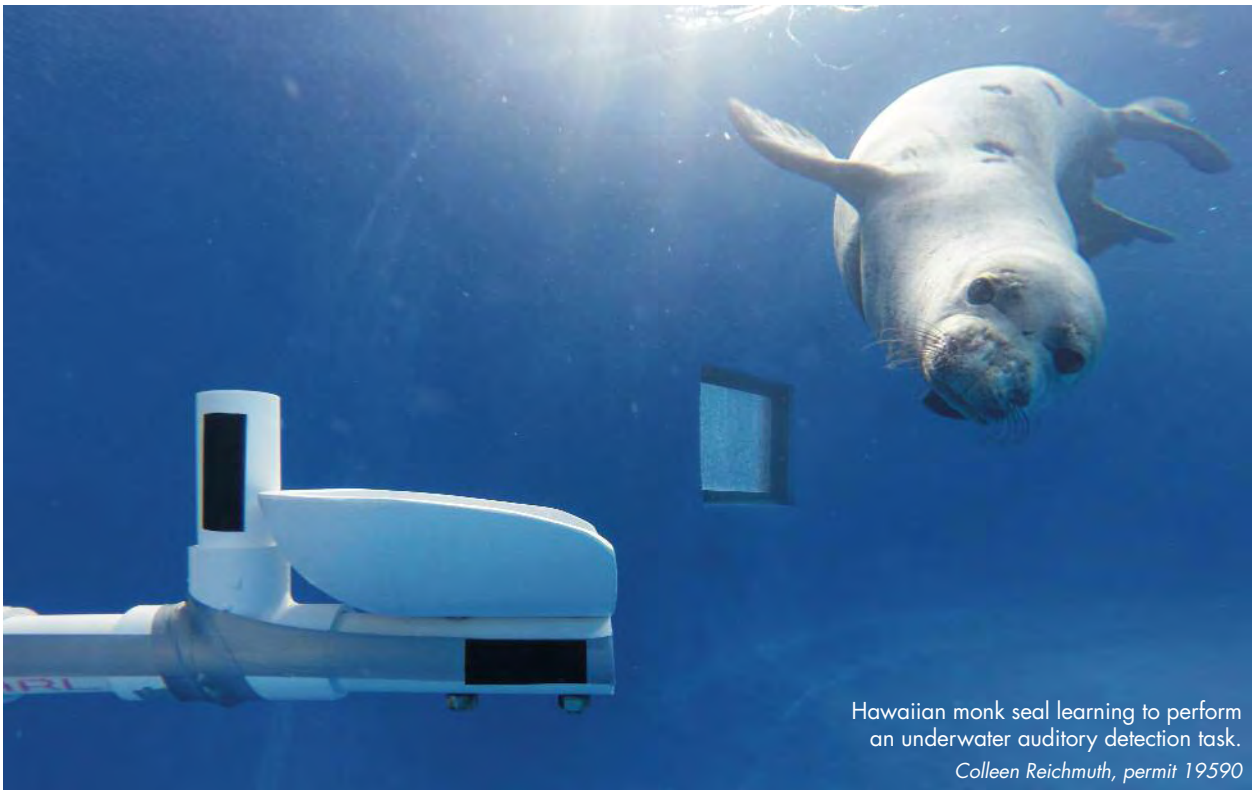
This project is obtaining reliable measures of auditory sensitivity—across the full frequency range of hearing—for a specially trained adult male Hawaiian monk seal. The resulting data will be used to generate both underwater and in-air audiograms that will help to support impact assessments of the Hawaiian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

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

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

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

Work during 2018 centered on testing underwater hearing and providing an initial description of



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

underwater sound production for the species. The underwater hearing test results revealed that Hawaiian monk seals hear better at lower frequencies than previously believed. The hearing range is generally consistent with other seals at lower frequencies. Best hearing appears to fall within a range of approximately 0.2 to 33 kHz. The high frequency roll-off is consistent with an early report concerning hearing in Hawaiian monk seals but occurs at lower frequencies than has been reported for other phocid seals (true seals). Sound production measurement efforts during 2018 included year-round sound recordings validated by video data that are used to describe call repertoire and to determine seasonal patterns in vocal behavior.

During 2019 project efforts were directed to in-air hearing measurements, as well as continuing underwater sound production recordings. This work entailed characterizing the ambient noise, mapping the sound field and calibrating stimuli. The monk seal was trained for the behavioral auditory task within the testing enclosure prior to testing. The auditory thresholds tested across the frequency range of hearing in air encompassed 11 frequencies from 0.1 to 33.2 kHz. Results suggest that in-air hearing is poor for monk seals (which are in the Monachinae subfamily), in contrast to the northern seals in the Phocinae subfamily, which have exceptional in-air hearing.

The team continued audio and video recordings of underwater sound production, analyzing spectrograms and cataloging call types and seasonal patterns. The researchers carefully validated that all calls cataloged were produced while the seal was underwater. They have characterized at least six call types, and the calling spectrum overlaps the range of best hearing. Seasonal patterns suggest that male Hawaiian monk seals have a long reproductive period.


Hawaiian monk seal.

Manuscripts on the testing are in preparation, with publication targeted for 2020.

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

About the Principal Investigators

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

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

Key collaborators: Graduate students Kirby Parnell, University of California, Santa Cruz and University of Hawai'i; Brandi Rusher-Hill, University of California, Santa Cruz.

TTS in Harbor Seals Due to Fatiguing Sound of Several Frequencies

Principal Investigator: Ron Kastelein
Project Status: Ongoing, Project 33

NEED

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

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

PROJECT

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

To evaluate the frequency-dependent susceptibility of seal hearing, the project goals are to

1. Determine the susceptibility to TTS of harbor seals over their entire hearing range
2. Determine TTS onset, relationship between sound exposure level (SEL, a unit which contains both the exposure level and the exposure duration) and TTS after the harbor seals have been exposed to sounds of various frequencies
3. Determine which hearing frequency is most affected by each fatiguing sound frequency. Generally, a higher hearing frequency is affected than the frequency of the fatiguing sound that a mammal is exposed to
4. Determine the recovery rate of hearing after the fatiguing sound stops
5. Based on the information derived for goals 1–3, construct equal-TTS curves (one of which will be the TTS onset curve).

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

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

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

frequency, and several post-exposure hearing threshold measurements to determine the rate of recovery of hearing.

Seven fatiguing sounds have been tested: a continuous tone (6.5 kHz) and continuous 1/6-octave noise bands centered at 0.5, 1.0, 2.0, 16, 32 and 40 kHz. Control sessions are conducted for each hearing test frequency. Initial exposure duration was one hour per session. Each fatiguing sound was produced at five sound pressure levels (SPL). This approach provides insight into the relationship between TTS and SPL. Two or three hearing frequencies were tested per fatiguing sound frequency (often the highest TTS occurs at a higher frequency than the frequency of the fatiguing sound). Each exposure level/hearing frequency was tested multiple times.

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

Ron Kastelein, SEAMARCO

While the original project plan included fatiguing sounds at nine frequencies, two of the planned lowest frequencies (125 and 250 Hz) could not be tested without generating high-level harmonics in the pool. However, tests at the other frequencies revealed that seal hearing is much less susceptible to TTS due to low frequency. Tests at 0.5 and 1.0 kHz even required exposures of two, four and six hours to reach TTS.

Two manuscripts from this project, including one on TTS due to 16 kHz frequencies, were published in 2019. The manuscripts on TTS due to 32 and 40 kHz frequencies study will be published in 2020. (See the LMR Publications section at the end of this report for 2019 citations.) Data analysis is due to be completed in March 2020. A final manuscript, which includes the TTS due to 0.5, 1 and 2 kHz exposures, is in preparation for publication.

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

About the Principal Investigator

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

New Start Projects

Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales

Principal Investigator: Dorian Houser
Project Status: New Start, Project 37

NEED

SOST Need: Development of Audiograms for Mysticetes

There is a need to improve understanding and measurement of auditory capabilities and sensitivities of low-frequency cetaceans (mysticetes) to anthropogenic sound. Research necessary to generate a mysticete audiogram includes developing and validating finite element modeling (FEM) methods, developing and testing *in-situ* auditory evoked potential (AEP) measurement methods for mid- and high-frequency hearing sensitivities of mysticetes, developing tools for AEP measurements below 1 kHz, evaluating behavioral response methods and identifying other appropriate approaches or methods.

PROJECT

This project, funded in cooperation with the Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life (SOST ITF-ONML) (see the Partnership section, page 105, for more information), is focused on obtaining *in-situ* AEP measurements of the hearing sensitivity of mysticetes. AEP methods involve measuring small voltages that the brain and auditory nervous system generate in response to sound. Using AEPs to determine hearing sensitivity has been common practice in human and terrestrial animal research for decades. Over the last two decades, the technology also has been used routinely to test hearing in odontocetes both small (e.g., dolphins and porpoises) and large (e.g., beluga, pilot and killer whales). The project team plans to obtain AEP hearing thresholds for minke whales (*Balaenoptera acutorostrata*), which will provide the first direct measurement of hearing in a mysticete.

The project team is proposing to measure the hearing of minke whales temporarily confined in a fjord off the Norwegian coast. They will use AEP methods specifically modified for these animals. The research plan focuses on small (3-5 meters long) juvenile minke whales because they are more suitable for handling and should have good hearing capabilities. Juvenile minke whales are similar in size to wild beluga whales that have been previously captured for AEP testing. The project goal is to conduct AEP hearing tests on 12 healthy animals deemed fit for testing by a marine mammal veterinarian at the time of initial capture.

> The results of this study will be invaluable to regulators, scientists, the U.S. Navy and others concerned with the potential impact of sound on mysticetes.

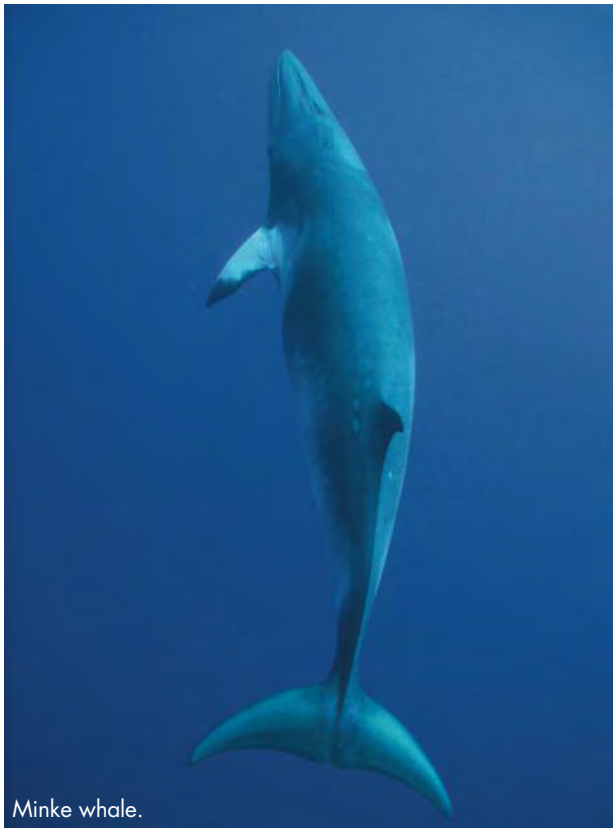
It is anticipated that the modifications to AEP methods will largely consist of adapting approaches previously worked out on smaller cetaceans with a special focus on sound delivery and AEP recording at lower frequencies. Researchers will use both broadband and narrowband acoustic stimuli to optimize procedures and determine the shape of the minke audiogram. Upon conclusion of testing, each whale will be fitted with a satellite tag to monitor its behavior after release.

All necessary permits are in place and the project was approved by the National Marine Mammal Foundation (NMMF) Institutional Animal Care and Use Committee (IACUC). In addition, a

Department of Defense (DoD) veterinarian has reviewed and approved a Bureau of Medicine and Surgery animal use protocol in compliance with the DoD Instruction, "Use of Animals in DoD Conducted and Supported Research and Training." A safety protocol has been developed to ensure the health and safety of the animals and researchers during the entire effort.

The project is effectively a two-phased project with a go/no-go decision by the sponsors between phases. Efforts in the first phase will include planning for and conducting one full field season. Based on the results of the first field season, the research team will present findings and recommendations to the funding agencies to determine if work will continue.

This study's results will be invaluable to regulators, scientists, the U.S. Navy and others concerned with the potential impact of sound on mysticetes. Determining frequency-specific information, particularly the upper-frequency limit of hearing and the region of best sensitivity, will provide data needed for validating models of hearing in mysticete whales. Additionally, determining low-frequency thresholds will provide information needed to establish auditory weighting functions for mysticetes, which currently lack empirical data. Techniques developed during the minke whale hearing tests also will facilitate future audiometric measurements on other mysticete species.


Minke whale.

Data will be made available through peer-reviewed publications and incorporated into a central repository of marine mammal evoked potential hearing data (The Cetacean Evoked Potential Audiometry Database). Methods developed for testing of mysticete hearing will be described in peer-reviewed publications and will be used to train stranding personnel that could have the opportunity for further testing with stranded mysticetes.

About the Principal Investigator

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

Co-PIs are Jason Mulsow, Ph.D. (NMMF), Petter Kvadsheim, Ph.D. (Norwegian Defence Research Establishment (FFI)), Lars Kleivane, MSc (LKARTS Norway), James Finneran, Ph.D. (U.S. Navy Marine Mammal Program (MMP)) and Rolf Arne Ølberg, DVSc (Kristiansand Dyrepark)

Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds

Principal Investigators:
Rebecca Dunlop, Michael Noad
Project Status: New Start, Project 38

NEED

SOST Need: Development of Audiograms for Mysticetes

There is a need to improve understanding and measurement of auditory capabilities and sensitivities of low-frequency cetaceans (mysticetes) to anthropogenic sound. Research necessary to generate a mysticete audiogram includes developing and validating finite element modeling (FEM) methods, developing and testing *in-situ* auditory evoked potential (AEP) measurement methods for mid- and high-frequency hearing sensitivities of mysticetes, developing tools for AEP measurements below 1 kHz, evaluating behavioral response methods and identifying other appropriate approaches or methods.

PROJECT

This project, funded in cooperation with the SOST ITF-ONML (see the Partnership section, page 105, for more information), is addressing the portion of the need related to evaluating behavioral response methods for generating an audiogram. The project team will measure the behavioral response of migrating humpback whales (*Megaptera novaeangliae*) to tones of various frequencies to infer their hearing sensitivity at each frequency. These behavioral response experiments will be a proxy for audiometric measurements to estimate hearing sensitivity.

A series of field experiments, the first planned for summer 2020, will be conducted in a unique site near Queensland, Australia. The field experiments will involve deploying a sound source from a vessel and playing upsweep tones at various frequencies (one frequency per treatment) to approaching whales. The source level of the tone will be held constant, but as the whales approach the sound source, the tones will become louder until the whales change behavior, likely by avoiding the source vessel. This will be repeated multiple times, using different whales, for each frequency. There will also be a similar number of trials in which the vessel will be present but no tones are transmitted to provide a control sample.

> The resulting information on humpback whale hearing will help regulators, industry and the U.S. Navy to model the potential effects of noise-producing activities on humpback whales.

A four-phase experimental routine will be followed.

1. Tagging phase—Attempt to tag an adult whale in the group.
2. Before phase—Follow the group without interference to observe normal behavior and move the source vessel into position close to the projected path of the group.
3. During phase—Operate the sound source as the group approaches until the signal is detected and the whale responds by avoiding the acoustic source/vessel.
4. After phase—Conduct acoustic measurements and recover tags.

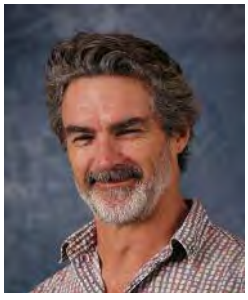
Humpback whale.
Cetacean Ecology and Acoustics Laboratory

The study site provides several benefits, including much lower noise levels than many ocean sites. The site's acoustic environment has been extensively measured and characterized. Eleven previous field seasons at this site provide a wealth of background data on whale movements, normal behaviors and abundance, which will support tagging efforts and facilitate detecting responses to the sound source.

The resulting information on humpback whale hearing, including data on how well humpback whales can hear under ambient conditions, will help regulators, industry and the U.S. Navy to model the potential effects of noise-producing activities on humpback whales. Results also will inform hearing models that have been developed for mysticetes, will help to validate and integrate the modeling approach with real data, and will provide a robust measure of humpback whale responses to tones under realistic conditions, which could be used in modeling the effects of various sound sources.

About the Principal Investigators

Rebecca Dunlop is a senior lecturer in physiology and animal behavior at the School of Veterinary Science, University of Queensland, Australia. Dr. Dunlop earned her Ph.D. in neuroethology from The Queen's University of Belfast, Ireland. Her current research focuses on humpback whale social communication, physiology and the effects of anthropogenic noise.



Michael Noad is an associate professor at the School of Veterinary Science, University of Queensland, Australia. Dr. Noad earned his Ph.D. from the University of Sydney, Australia. His current work focuses on the evolution and function of humpback whale song, population ecology and effects of noise.

Use of "Chirp" Stimuli for Non-invasive, Low-frequency Measurement of Marine Mammal Auditory Evoked Potentials

Principal Investigator: James Finneran
Project Status: New Start, Project 39

NEED

N-0202-19: Development of Audiograms for Mysticetes

There is a need to improve understanding and measurement of auditory capabilities and sensitivities of low-frequency cetaceans (mysticetes) to anthropogenic sound. Research necessary to generate a mysticete audiogram includes developing and validating finite element modeling (FEM) methods, developing and testing *in-situ* auditory evoked potential (AEP) measurement methods for mid- and high-frequency hearing sensitivities of mysticetes, developing tools for AEP measurements below 1 kHz, evaluating behavioral response methods and identifying other appropriate approaches or methods.

PROJECT

This project is focusing on one of the methods noted in the Need section—examining potential tools to inform AEP measurements below 1 kHz in mysticetes. AEP methods involve measuring small voltages that the brain and auditory nervous system generate in response to sound and are measured and used to evaluate auditory capabilities. The goal of this project is to determine the extent to which an upward "chirp" stimulus—a sound whose frequency increases with time—can increase AEP amplitudes at lower frequencies in marine mammals. The chirp stimuli will be specially designed so that the rate at which the frequency sweeps upward optimally matches the (species-specific) properties of the inner ear. Experimentally determined properties of the "optimal" chirp will then be compared with anatomical properties of the inner ear, which could support predicting optimal chirp for other species, such as mysticetes, for which only anatomical data exist.

The project has three broad objectives.

1. Determine the extent to which *broadband* upward chirps increase AEP amplitudes and how the effectiveness of a broadband chirp varies with chirp sweep rate, duration, frequency range and level.
2. Determine the extent to which *narrowband* upward chirps increase AEP amplitudes compared to tone burst stimuli and if narrowband chirps provide advantages (compared to tone bursts) for marine mammal auditory threshold testing.
3. Determine if optimal chirp properties can be predicted from cochlear traveling wave speed (TWS) estimates and/or anatomical measurements of the cochlea.

The data collected from this effort will contribute to developing tools needed to advance AEP measurements below 1 kHz.

Data will be collected with bottlenose dolphins (*Tursiops truncatus*) and California sea lions (*Zalophus californianus*). These species are available at the U.S. Navy Marine Mammal Program and they represent echolocating cetaceans with good high-frequency (10–100 kHz) hearing and marine carnivores with good mid-frequency (1–10 kHz) hearing. Sea lions provide a means of approximating the frequency range of hearing expected for some mysticetes while testing a more accessible species.

During 2020 the project will focus on measuring AEPs to broadband stimuli and estimating cochlear TWS and optimal chirp properties from derived band AEP data.

The data collected from this effort will contribute to developing tools needed to advance AEP measurements below 1 kHz. Given the anticipated difficulty in measuring AEPs in mysticetes, technical innovations that result in increased AEP amplitude (and thus improve AEP detectability) will be of great benefit to directly obtaining information on hearing in mysticetes.

Data resulting from this project will be presented at scientific conferences, published in peer-reviewed scientific journals, technical reports and/or white papers and will be disseminated to Navy environmental planners. Methods and processes for enhancing low-frequency AEP amplitude could then be incorporated into efforts to directly measure AEPs in mysticetes (or other marine mammals).

About the Principal Investigator

James Finneran has worked as a research scientist at the Naval Information Warfare Center (NIWC) Pacific since 2002, investigating marine mammal echolocation and marine animal auditory capabilities and studying the physiological effects of sound on marine animals. Dr. Finneran earned his Ph.D. in mechanical engineering from The Ohio State University.

Key contributors: Dr. Jason Mulsow, National Marine Mammal Foundation; Dr. Robert F. Burkard, University at Buffalo.

Sea lions.
Cordelia Shea

Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles

Principal Investigators:
Aran Mooney, Wendy Piniak
Project Status: New Start, Project 40

NEED

N-0208-19: Turtle TTS Feasibility Study

The Navy, National Marine Fisheries Service (NMFS) and other federal agencies require quantitative thresholds to examine the potential impacts of underwater sound on protected species. Basic audiometric information is available for some sea turtle species, however, data on the susceptibility of sea turtles to noise induced hearing loss (threshold shifts) is lacking. There is a need to obtain auditory temporary threshold shift (TTS) information for sea turtles. Due to their protected status under the Endangered Species Act, it is necessary to first determine the feasibility of generating TTS in a closely related surrogate—a non-ESA listed turtle species (e.g., red-eared slider, eastern painted turtle, pond slider, etc.). If feasible, steps to obtain TTS information for an ESA-listed sea turtle may be undertaken in follow-on research efforts.

PROJECT

This project is examining auditory TTS in two species of freshwater aquatic turtles and will potentially provide the cumulative sound exposure levels and durations that induce these TTS. The work also will include examining the turtles' ear anatomy to support physiological comparisons between freshwater and marine turtle hearing apparatus. This will help to identify potential TTS susceptibility of sea turtles based on freshwater turtle data. Results will provide researchers, managers and stakeholders critical data to improve estimates of acoustic effects to both freshwater and sea turtles and to inform the development of appropriate mitigation measures to reduce potential effects to sea turtles from low-frequency anthropogenic sound. This project is co-funded by the LMR program and NOAA.

Initial underwater hearing measurements and TTS assessments will be conducted with two freshwater turtle species—the eastern painted turtle (*Chrysemys picta picta*) and red-eared slider (*Trachemys scripta elegans*). Physiological AEP methodology will be used. Testing two species will increase sample sizes, which will support both developing robust TTS measurement methods and identifying if there are methodological challenges/differences between the species. Additionally, comparing TTS onset in the two surrogate taxa will contribute to understanding potential TTS variability between turtle species. The AEPs will be followed by sound exposure trials and anatomical imaging as summarized below.

AEP testing

Baseline hearing sensitivity will be measured by recording AEPs, a rapid, non-invasive technique that can be used to measure hearing in a diverse array of taxa including fishes, squid, seabirds, odontocetes, manatees, pinnipeds, sharks and sea turtles.

Loggerhead sea turtle.
NOAA

Green sea turtle.

Initial hearing thresholds to determine a baseline audiogram will be measured at a variety of frequencies between 50 and 5,000 Hz (with additional frequencies added as needed). This method is well-established and encompasses the full anticipated range of turtle hearing. At each frequency, sound levels will be decreased until AEP responses can no longer be detected (threshold).

Sound exposure trials

Sound exposure trials will explore duration and sound pressure levels required to induce TTS onset and develop a TTS onset predictive curve. The trials will expose turtles to broadband white noise that spans their auditory frequency range and is likely to cause TTS. Eastern painted turtles and red-eared sliders can detect acoustic signals between 30 and 5,000 Hz with maximum sensitivity <1,000 Hz. Fatiguing noise sound pressure levels will start at 140 dB and increase up to 160-170 dB sound pressure level (SPL), after which durations will be increased to increase overall sound exposure level (SEL).

Anatomy

The project will also examine the similarities and potential differences of the auditory anatomy of control animals and those exposed to sound to identify potential short- and long-term anatomical effects of TTS. Auditory hair-cell damage and loss in some marine taxa have served as indicators of sound exposure and these indicators could apply to turtles. Defining methods by which to assess damage would support examining other turtle species in the future.

Three methods are being considered. The first involves using x-ray computed microtomography

(μCT) to examine morphology on the micro-scale. Although μCT on turtle ears has not been previously conducted and using these methods to gauge hair cell health and status may be challenging, it offers a good, non-invasive first step. Second, researchers may seek to image auditory hair cells using fluorescent immunohistochemical procedures (which provide high resolution imaging at a cellular level) and other readily available methods used in an array of animals, from fish to invertebrates and mammals. The third imaging option is scanning electron microscopy.

The audiograms and TTS data produced by this research will provide experts with appropriate data when developing the next phase of TTS criteria.

Based on the results of these efforts, the team will explore dose-dependent effects to begin to create a noise-based, dose-dependent model of TTS. This will allow regulators and data users to predict the sound levels and durations that may produce TTS onset in turtle species. Project products also will outline the methods likely needed to induce and measure TTS in sea turtles, if feasible.

During 2020 the team plans to complete the initial AEP recordings and TTS onset evaluation, attempt to induce TTS at additional hearing frequencies, and complete initial TTS analyses. Additional efforts during 2020 will include developing hair cell imaging methods, analyzing data and writing reports.

Because no TTS data currently exist for turtles, the audiograms and TTS data produced by this research will provide experts with appropriate data when developing the next phase of TTS criteria. The data also will inform analyses of the effects of sound-producing activities on sea turtles.

Results will be provided to the project funders and the sea turtle and marine bioacoustics research and management communities through regular reports, conference presentations and publications in peer-reviewed scientific journals. The major products of this proposed research will be underwater audiograms and underwater TTS onset data for two species of freshwater turtles. The project will also provide protocols that will contribute to investigations of noise-induced hearing loss in other turtle species, including sea turtles.

About the Principal Investigators

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

Wendy Dow Piniak is a visiting assistant professor in the Marine Science and Conservation Division of the Nicholas School of the Environment at the Duke University Marine Lab. Dr. Piniak's research focuses on sea turtle acoustic ecology. She has experience measuring turtle hearing and conducting field studies examining sea turtle behavioral responses to sound. Dr. Piniak holds a Ph.D. in marine science and conservation from Duke University.

INVESTMENT AREA 2
DATA PROCESSING AND ANALYSIS TOOLS

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

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

This investment area also aligns with the Navy's strategy to increase the use of machine computing tools to optimize data and analytics. Developing tools to automate the processing of large amounts of data can reduce costs, increase productivity and provide consistency. Research on data analysis tools can improve existing methods or foster development of new methods, both of which provide improved data products and results. Projects in this area can include new detection and classification algorithms, improvements to software programs or development of novel analytical methods.

The following section includes summaries of three ongoing and three new start projects. The ongoing projects are

1. Project 17—Blue and Fin Whale Density Estimation in the Southern California Offshore Range Using PAM Data
2. Project 31—DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling
3. Project 36—Analytical Methods to Support Development of Noise Exposure Criteria for Behavioral Response.

The new start projects are

1. Project 42—ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation
2. Project 43—MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance
3. Project 44—Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales.

Fin whale.
Jeff Foster, permit 16111

Ongoing Projects

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

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

NEED

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

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

PROJECT

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

To estimate density from passive acoustic data, it is necessary to know the animals' average call rates, the call detection range and the probability of call detection within that range. The project is leveraging results from work completed under ONR MMB funding, using long-term passive acoustic data sets from SOCAL and using acoustic tag data from the SOCAL Behavioral Response Study and other tagging studies in the area. In addition, this project is including data collected using tags with medium-duration attachments, as they became available. These multi-day tag data provide more information on variations between nighttime and daytime behaviors influencing calls.

The main goal of this project is to develop and evaluate methods for generating spatially and temporally explicit density estimates.

Estimating call detection ranges and probability of call detection includes developing acoustic propagation models. Obtaining measures of some propagation parameters, such as bathymetry and sediment layer properties (including thickness), has been challenging. The models that will be used for this analysis will largely rely on a previously completed LMR project by Tyler Helble (Improving the Navy's Automated Methods for Passive Underwater Acoustic Monitoring of Marine Mammals).

Blue whale.
Ana Širović

Fin whale.
Ana Širović

Work during 2017 and 2018 focused on conducting field surveys to collect new data, analyzing call rates for blue whales and refining and testing models for blue whale cue rate estimation that can be applied to time series of acoustic detections. Data collection in 2018 also included capturing fin whale data.

During 2019, data analyses and model evaluation and refinements continued. Work focused on completing transition of the acoustic propagation models and probability of detection models for both blue and fin whales. The team also started work on developing an automated detector for efficiently extracting blue and fin whale social calls. The machine learning methods tested are showing promise with analysis speeds that will be about 100 times faster than real time.

Work in 2020 will focus on exploring sources of variability in cue rate and considering how that variability affects density estimates potentially produced by the methods developed as part of this project.

About the Principal Investigator

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

Key collaborators: John Calambokidis, Cascadia Research Collective; Jeppe Rasmussen, TAMUG; Tyler Helble, Naval Information Warfare Center.

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

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

NEED

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

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

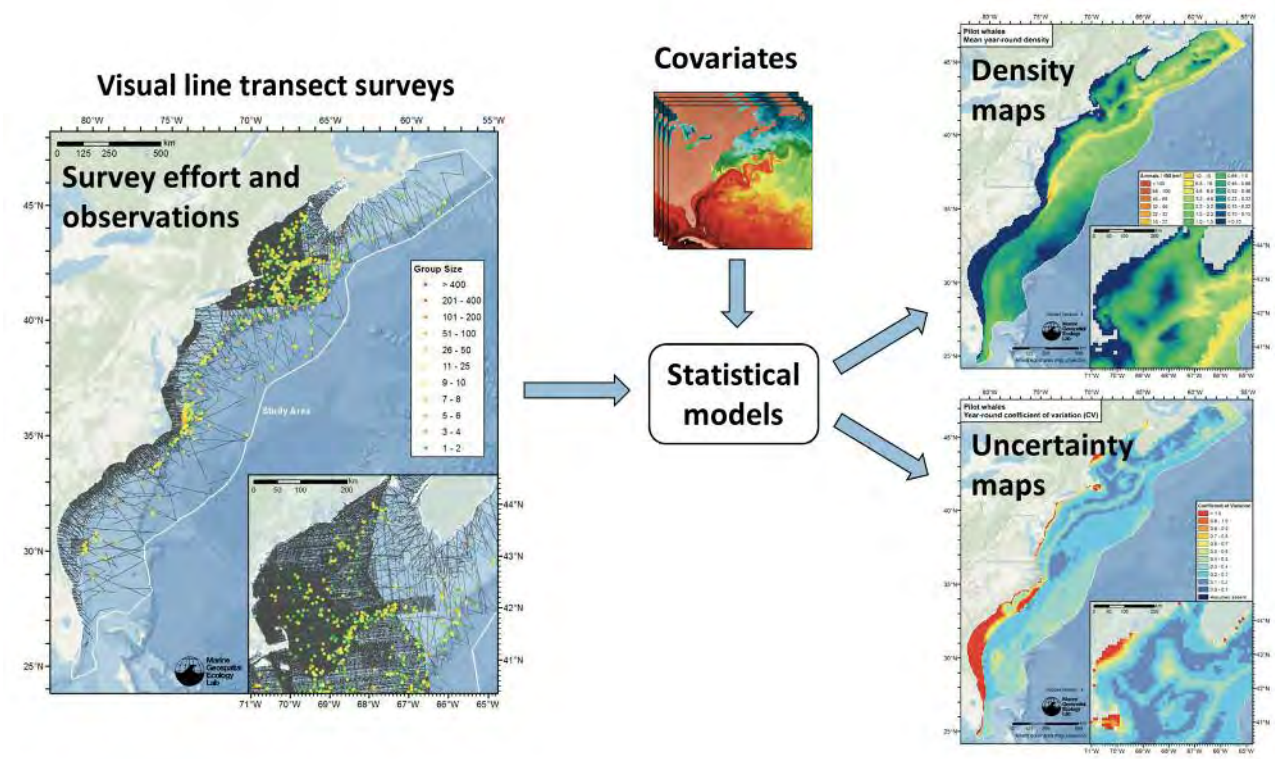
PROJECT

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

In this project, a working group is focused on developing and implementing innovative approaches to improve spatial modeling methods used to characterize seasonal abundance and distribution of marine species. The participating organizations lead in the development and application of the survey and analysis methods used—the University of St Andrews, Duke University and the four regional NOAA Fisheries labs—and include the parties largely responsible for collection and analysis of transect data used in Navy impact assessments. Goals include producing software tools that implement new approaches and providing statistical support to those tasked with undertaking density surface modeling for the Navy. The team will develop concrete guidance on best practices in this type of modeling.

The overall working group meets annually to review progress and priorities. The group's third meeting was held prior to the World Marine Mammal Conference in December 2019. This also offered the venue for the second of three planned public workshops, during which the DenMod working group presented the current state of project efforts and solicited input from

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



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

Jason Roberts, Duke University

workshop attendees. Reports from these workshops can be found at the DenMod website (synergy.st-andrews.ac.uk/denmod).

Several technical sub-groups have been organized to focus on key issues. There now are seven topics that have been assigned to sub-groups. Each is discussed briefly below.

1. Uncertainty estimation—There are numerous sources of uncertainty when modeling the spatial distribution of animals that are hard to see (and sometimes submerged) in a dynamic environment. This sub-group focuses on correctly quantifying the effects of these uncertainties on the final uncertainty in maps and abundance estimates. A tool for variance propagation has been developed in the R programming language and the sub-group met to test the variance propagation method within Southwest Fisheries Science Center density surface models. The group will continue to investigate sources of uncertainty from field data.
2. Extrapolation—The Navy requires density estimates in areas for which there are no data. Such extrapolation makes assumptions on the correctness of the model used. During 2019 this sub-group drafted a guidance document along with a software toolkit (dsmextra), available at densitymodelling.github.io/dsmextra. The sub-group is continuing work on how to address extrapolation when setting up a model.
3. Model unification—There are a wide variety of different modeling techniques that can be used to obtain spatially explicit estimates of density, but many of these lead to similar results. This sub-group has been looking at the similarities between existing methods to ensure that practi-

tioners are using the best possible methods and not investing time and resources in new methods that provide little benefit. They have completed a mathematical comparison of different spatial modeling approaches. Two peer-reviewed articles have been published and two more are being prepared. This topic will be revisited later in the project.

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

4. Workflow—A wide variety of data preparation and modeling workflows have evolved over time within the different organizations that provide density estimates to the Navy. The workflow sub-group is working to encapsulate this information. During 2019, the sub-group compiled a wiki of frequently asked questions that gives information on best practices and software/literature resources and includes a forum for discussion among those engaged in modeling. The wiki was reviewed by the broader DenMod group and is now publicly available online at osf.io/5eza8/wiki.

5. Pinnipeds—This sub-group was formed based on input from the project's first public meeting (2017). Pinnipeds raise unique issues when it comes to abundance estimation, as at-sea data are scarce, but counts from haul-outs and movement data from tags are common. Operating under separate funding, this sub-group is focused on working out how best to use and combine these disparate data.

6. Acoustic and visual data integration—This sub-group was formed following the second DenMod working group meeting in October 2018. It is investigating methods for integrating density surfaces estimates derived from visual surveys and from separate, but spatially and temporally overlapping, acoustic surveys. Work during 2019 focused on identifying possible data sets and establishing priorities for a case study.

7. Data integration—This sub-group, formally started during 2019, evolved from early discussions on integrating telemetry data into density surface modeling of pinnipeds. The group will consider data integration more broadly than pinnipeds and its main effort will be in year 4 of the project.

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

About the Principal Investigator

Len Thomas is Professor of Statistics and member of the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. He specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in forestry from the University of British Columbia.

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

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

Principal Investigators:
Len Thomas, Catriona Harris
Project Status: Ongoing, Project 36

NEED

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

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

PROJECT

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

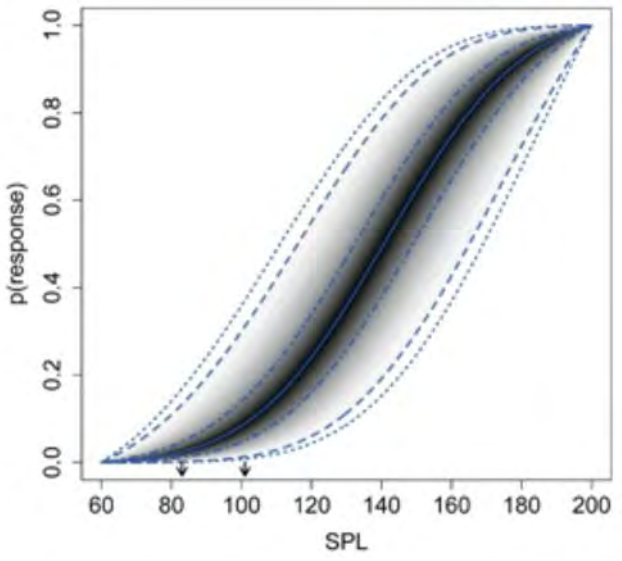
This project is focused on developing a computationally efficient model selection method that supports and expands upon the existing Bayesian hierarchical dose-response framework that has been and continues to be employed. Under the current approach, modeling more than six species or adding contextual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

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

The project team is building on outcomes of the ONR MMB-funded MOCHA (Multi-study Ocean Acoustics Human Effects Analysis) project (synergy.st-andrews.ac.uk/mocha) to develop a new model selection method. They are investigating alternative dose-response functional forms (e.g., biphasic functions), evaluating such functions across species and species groups using selected model selection methods and additional contextual variables. The methods will be tested using simulated data and multi-species data compiled during the MOCHA project, as well as newer data. The team will run analyses with a full data set and align outputs with identified requirements.

The project team also aims to derive exposure-response functions for each selected species group. They are evaluating explicitly how contextual variables contribute to outcomes. A priority dose metric to investigate is the range from the sound source to the whale.

During 2019, team members met with behavioral response study researchers to identify available data



An example of a Bayesian dose-response function developed during the ONR-funded MOCHA project.

Figure taken from Miller, P.J.O. et al. 2014. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. Journal of the Acoustical Society of America 135: 975-993

and formats. The team collated the data from controlled exposure experiments (CEEs) for a wide range of survey variables (e.g., exposure context, signal type, distance between source and animal, among others). Working with Navy environmental compliance experts, data were carefully reviewed to ensure data quality. Team members also began developing methods for model selection, reviewing algorithms to be used and improving existing code.

One additional need that arose from discussions with the Navy environmental compliance team was a better understanding of the balance between high resolution digital (DTAG) and low resolution (satellite tag) data from CEEs, and the effect of uncertainty in received levels from both data types on the resulting dose-response functions. The project team has therefore conducted a simulation study to investigate this and have presented the results to the environmental compliance team (example in figure above). The results will be made publicly available through a technical report (available at synergy.st-andrews.ac.uk/mocha) and peer-reviewed publication.

In 2020, the project will focus on testing and completing the model selection methods and applying methods to the full data set.

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

About the Principal Investigators

Len Thomas, Professor of Statistics at University of St Andrews and a member of the Centre for Research into Ecological and Environmental Modelling (CREEM), specializes in developing statistical methods to apply to ecological problems. Professor Thomas has a Ph.D. in forestry from the University of British Columbia.

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

New Start Projects

ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation

Principal Investigator: Tiago Marques
Project Status: New Start, Project 42

NEED

N-0205-19: Investigation of the Effects of Cue Rate and Cue Stability on Passive Acoustic Monitoring (PAM)-Based Density Estimation Methods

Marine mammal density estimates are a critical input for the Navy's acoustic effects modeling. While visual aerial or shipboard surveys are standard methodologies for estimating marine mammal density, they can be very expensive to conduct, are limited both in their spatial and temporal coverage, and are not effective at documenting cryptic species (species that are difficult to see). Estimating density using fixed-passive acoustic monitoring (PAM) has the potential to increase the amount of density data that can be used in the Navy's acoustic effects modeling. In some PAM-based density estimation (PAM-DE) methods, the "cue rate" or the marine mammal sound production rate is an important multiplier to get to a final density estimate. Cue rates can vary in marine mammals as a function of multiple factors, including time of day, year, group size, age, sex, behavioral state, season, bottom depth and location. Also cue rates often are determined from limited data sets and assumed to be representative for the species. The Navy needs recommendations of the most appropriate species for which to collect cue rate data and the appropriate cue rates to use in density estimates.

PROJECT

The ACCURATE project is designed to deliver a comprehensive, quantitative synthesis of the current state of knowledge on acoustic cue rates and cue rate stability for marine mammal density estimation from passive acoustics. The ultimate project goal is to determine the most appropriate cue rates to use in different contextual settings. The project will produce a comprehensive set of recommendations of the most appropriate means by which to advance this field to meet Navy needs. This information will be made publicly available to the wider scientific community involved in estimating density from passive acoustics.

The project team will

- Identify, review, compile and provide open access to all data available on cue rates (and their variability) across deep-diving and baleen whale species
- Develop methods to estimate cue rates from different data types (e.g., time-depth data) and for different taxa
- Apply these methods to species of interest for the Navy
- Explore the factors that determine cue rate variability over time and space
- Evaluate impacts of cue rate variability on density estimates from cue-based methods.

The project is beginning with an extensive bibliographic search for peer-reviewed papers and grey literature reports as well as contacting researchers involved in PAM work to understand existing, but unpublished, data sources. The project team will investigate different methods that could be used to estimate cue rates, and if different types of cues exist, what might be the optimal choice of cue for each species (e.g., regular clicks vs. buzzes, social vs. feeding sounds, etc.). The outcome will be a user-friendly data repository that enables Navy users to find the most appropriate cue rate to select in PAM-DE efforts for a given priority species and area.

Tagged sperm whale.
Rune Roland Hansen, Norwegian Animal Research Authority permit 2015/2232

The team will work with other researchers to process and analyze existing acoustic tag data to estimate cue rates for selected species. These will include at least Cuvier's beaked whale, Blainville's beaked whale and sperm whale. All cues and cue types from each tag will be counted to obtain a cue rate per tag. The estimated cue rate per tag will be combined into a simple cue rate per species.

Based on the initial project efforts, the team will explicitly assess how the cue rates change over time and space, in particular to understand the main drivers of cue rate variability for considered species and cues. A variety of factors might affect cue rates—time of day, sex, season, depth, species, population, sub-population, behavioral state and density itself. One objective is to define easy-to-measure covariates that can be used to predict cue rate. The project team will then build models predicting cue rate as a function of possible factors of interest, providing a framework to estimate cue rate for other times and places based on available covariates.

As information is collected, a series of case-study investigations will be considered to highlight specific scenarios of Navy interest. Examples include:

1. Evaluating methods for cue rate estimation in baleen whales. The team will work to identify call signatures in different data streams and generate methods to assign cues to a tagged animal.
2. Estimating cue rate from proxy data when acoustic data are not available. Hidden Markov models (HMMs) could be one approach that could support estimating the most likely, yet unobserved (i.e., hidden), behavioral state (e.g., feeding).

3. Investigating cue-rate variability of deep divers due to geographic region, behavioral state and group size and composition. This work will focus on sperm whales, which have highly-detectable echolocation clicks.
4. Investigating inter-click interval (ICI) patterns for deep divers. The ICI patterns can feed directly into evaluating factors driving cue rates such as time of day, season, geographic location, population or behavioral state.
5. Estimating cue rates when the automatic detector/classifier system influences the cue definition. This will use a combination of empirical and simulated data to investigate which 'cue' is the most stable for deep diving animals.

This project will advance the practical application of PAM-DE for Navy purposes.

As a final step, the project team will conduct a simulation exercise to evaluate the potential consequences of using biased cue rates. The project will also identify the potential effects of using different cues (with different characteristics) in cue-based density estimation exercises. This will provide guidance on interpreting the density estimates derived using cue rates from times and places other than the original PAM survey.

Efforts during 2020 will focus on identifying and compiling existing information on cue rates, as well as extracting and analyzing existing tag data to estimate cue rates for selected deep-diving species. If the information and funding indicate that they would be beneficial, specific case study investigations could be initiated during 2020.

Results will be provided through regular project reports as well as manuscripts that will be submitted to peer-reviewed journals. Presentations, and potentially a workshop, at marine mammal conferences will also disseminate information. Cue rates compiled and estimated throughout the project will be organized and available in a publicly available database.

Marine mammal density estimates are a critical element of the Navy's acoustic effects modeling, which supports environmental compliance. Passive acoustic monitoring potentially offers a cost-effective method to generate density estimates for a wide range of species across Navy priority areas. By addressing a fundamental aspect of PAM-DE—understanding cue rates and cue rate stability—this project will advance the practical application of PAM-DE for Navy purposes. The resulting repository of synthesized data will support future density estimation from passive acoustic monitoring.

About the Principal Investigator

Tiago Marques is a senior research fellow at the Centre for Research into Ecological and Environmental Modelling (CREEM), University of St Andrews, UK. Dr. Marques has been involved in a large number of projects related to different aspects of statistical ecology, mostly with an emphasis on estimating animal abundance considering a large variety of methods and taxa and with passive acoustic data in particular. He earned his Ph.D. in statistics from the University of St Andrews, UK.

Key contributors: Len Thomas, Danielle Harris, Doug Gillespie and Peter Tyack, University of St Andrews, UK; Cormac Booth, SMRU Consulting, University of St Andrews, UK; Ana Širović, Texas A&M University Galveston, USA; Susan Parks, Syracuse University, USA; Erin Oleson, Karlina Merkens, NOAA NMFS Pacific Islands Fisheries Science Center, USA; Simone Bauman-Pickering, UC San Diego, Scripps Institution of Oceanography, USA.

MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance

Principal Investigator: Cormac Booth
Project Status: New Start, Project 43

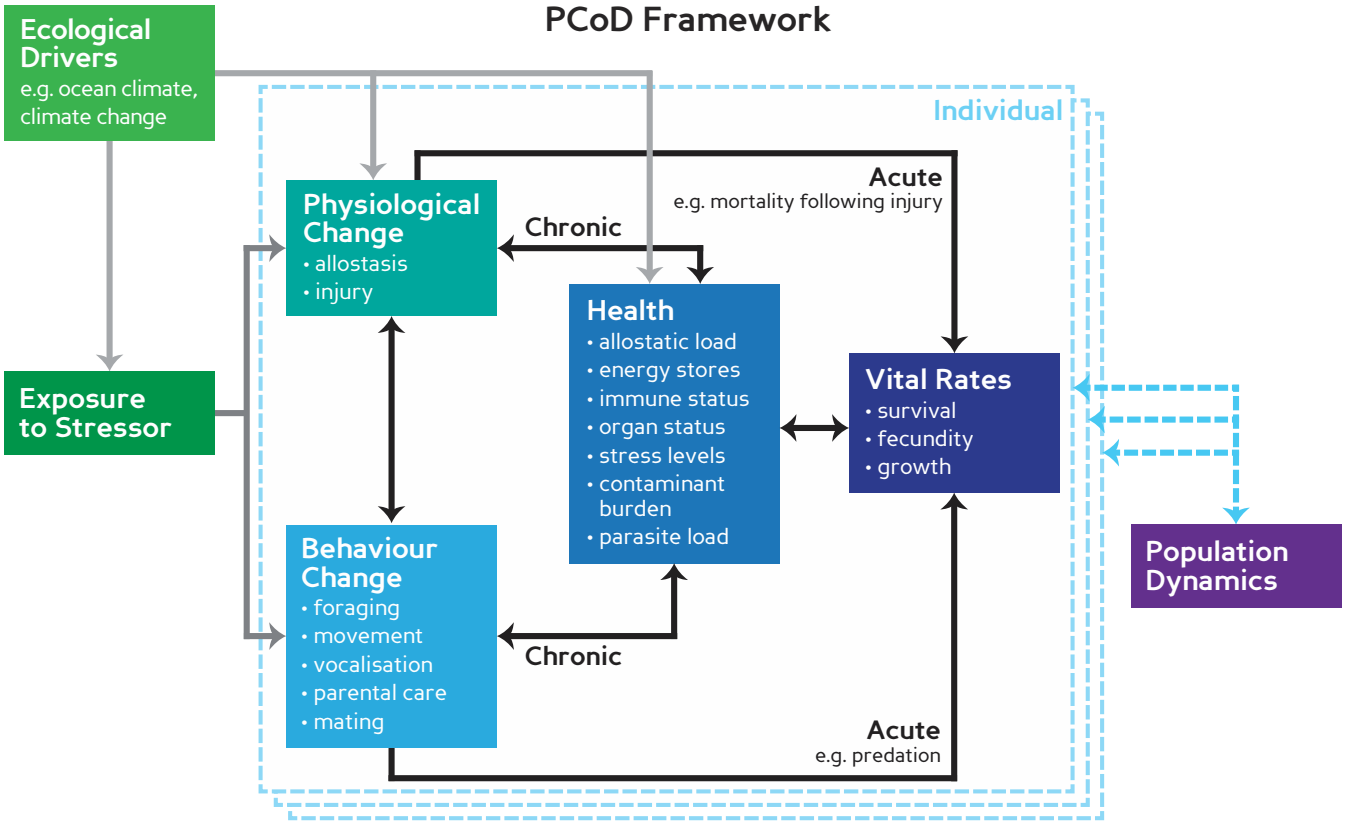
NEED

N-0207-19: Identification of Monitoring Priorities for Studying the Population Consequences of Disturbance on Marine Mammals

The population consequences of disturbance (PCoD) framework provides a conceptual framework which can be used to forecast a plausible range of outcomes for the possible effects of Navy activities on marine mammals. However, significant data gaps exist and it may take decades to fill these gaps. There is interest in identifying current methods for monitoring populations subject to disturbance that may also provide insights into the processes through which disturbance may affect these populations. The Navy is interested in a study that will inform the Navy Marine Species Monitoring program in terms of the methods and approaches that will enable the future ability to conduct PCoD analyses.

PROJECT

The overall objective of the MSM4PCoD project is to review the U.S. Navy Marine Species Monitoring (MSM) program to date and identify how current monitoring efforts could be adapted to supply appropriate data for future analyses of the consequences on marine mammals from possible disturbance by Navy activities. A working group supported by ONR MMB previously developed a mathematical framework for assessing PCoD. However, the PCoD framework requires a specific set of input data. It is critical to identify the data gaps that need to be filled in order to improve such models. This project will assess how well current Navy MSM program efforts can support PCoD analyses and recommend what could be improved.



The project team will begin by holding a workshop with Navy stakeholders to go over monitoring objectives and efforts to date and to discuss and potentially refine the scope of the project. Following the workshop, the team will pursue the project's three core steps.

1. Review applicable current and historical MSM projects and methodologies for priority areas and species and compile information into a reference database. This will include assessing the monitoring that has been conducted over the past 10-15 years of the MSM effort. For each monitoring study, the team will document the methods employed, the species sampled and the sample sizes obtained for different species/method combinations. The elements of monitoring determined to be relevant for PCoD will be compiled into a database.

2. Select suitable metrics for monitoring populations of deep diving odontocetes and large baleen whales using PCoD models that already exist or are currently in development. The results of the first step will be used to identify appropriate metrics or population characteristics that may be suitable for monitoring, and that could support PCoD analyses. The modeling outputs developed (and conclusions drawn) from previous PCoD-related projects will help to define the most appropriate metrics for the power analyses planned in the third step.

North Pacific right whale.
Brenda K. Rone, permit 782-1719

> This [project] offers the opportunity for Navy monitoring of consequences to target those species and populations best studied for identifying PCoD.

3. Conduct power analyses to assess the power of these metrics to inform PCoD analyses when collected within existing MSM projects, and determine the effort required to increase this power. Power analyses ensure sample sizes are sufficiently large to allow detection of an effect, such as changes in population size and demographics. Conducting power analyses on information from the monitoring program will indicate whether MSM efforts to date can support PCoD analyses and will help to identify what efforts would be required for different species/method/metric combinations. A series of power analyses for a minimum of two priority case study species (likely one deep-diving odontocete and one large whale species), as determined by the most suitable species from the MSM review, are expected.

Power depends on effect size (in this case magnitude of the long-term decline or sudden decrease) and so an important early task is to develop a range of scenarios for what determines a biologically meaningful change. After the initial power analyses, a set of simulation scenarios will be developed to determine the amount and type of sampling effort that would be required for different approaches to inform PCoD in the future.

The results of these efforts will be synthesized in a report that also provides recommendations for how the MSM program could inform PCoD analyses.

Efforts during 2020 will include holding a workshop that includes all Navy stakeholders to give an overview of the MSM program effort to date and discuss how to best focus the project on meeting the Navy's need for recommendations.

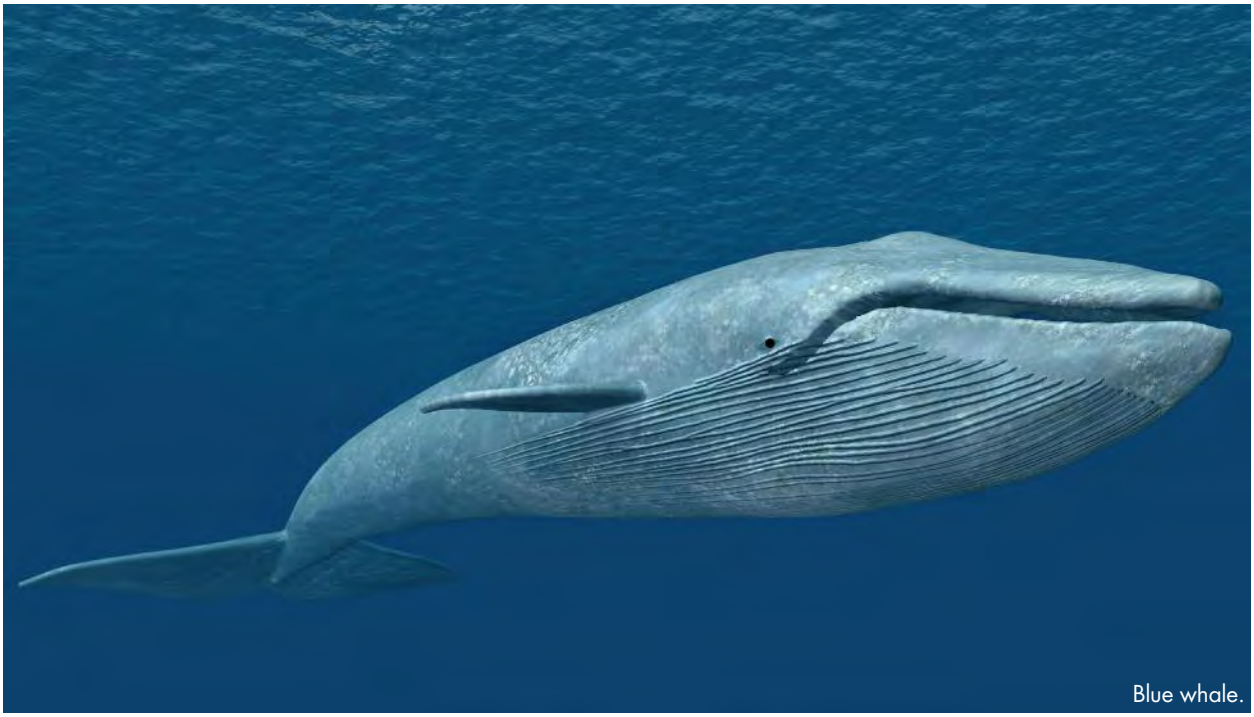
Results will include a set of practical recommendations of how PCoD elements could be incorporated into existing MSM efforts. This offers the opportunity for Navy monitoring of consequences to target those species and populations best studied for identifying PCoD. This will help to enhance the information collected and the analyses produced by marine species monitoring, which will increase monitoring benefits.

Products will include a database that catalogs the MSM program effort carried out to date on priority species in priority regions that might inform PCoD analyses, a spreadsheet of the data and a database guide. A report on results and recommendations will be provided to the Navy and shared through conference presentations and manuscript submissions to peer-reviewed journals.

About the Principal Investigator

Cormac Booth is Principal Scientist at SMRU Consulting, University of St Andrews, UK. Dr. Booth has served as lead scientist and project manager for multiple projects involving investigating the potential impacts of marine activities on marine mammal species, including a number of population consequences of disturbance (PCoD) projects. He has extensive experience in marine mammal biology, statistics and acoustics. Dr. Booth earned his Ph.D. at the University of St Andrews, UK.

Key contributors: John Harwood, Ursula Verfuss and Rachael Sinclair, SMRU Consulting, University of St Andrews, UK; Len Thomas, CREEM, University of St Andrews, UK.



Blue whale.

Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales

Principal Investigators:
Susan Parks, Len Thomas
Project Status: New Start, Project 44

NEED

N-0204-19: Demonstration and Validation of Passive Acoustic Monitoring (PAM)-based Density Estimation Methods Using Visually-verified Survey Data

Marine mammal density estimates are a critical input for the Navy's acoustic effects modelling. While traditional ship and aerial visual survey estimates of marine mammal density are standard methodologies for obtaining density estimates, they are very expensive to conduct, are limited in their spatial and temporal coverage and are not effective at documenting cryptic species (species that are difficult to see). The use of fixed-PAM for density estimation has the potential to increase the amount of density data in all U.S. waters and Navy ranges that can be used in the Navy's acoustic effects modeling. The Navy is interested in demonstrating and validating fixed PAM-based density estimation methods using vessel or shore-based visual surveys on species that have a high confidence level in being sighted.

PROJECT

This project will couple shore-based observations with a continuous acoustic recording array to obtain acoustic cues (i.e., vocalizations) for density estimation in a Brazilian population of southern right whales (*Eubalaena australis*). This population offers a useful study opportunity because the population travels close to shore in areas with elevated hillsides suitable for concurrent fixed passive acoustic monitoring and visual observation of individuals. Previous studies with southern right whales from multiple habitats have demonstrated that the acoustic repertoires of all right whale species are similar, with the same call types described for each species. The southern right whale can thus serve as a proxy for the highly endangered North Atlantic right whale (*Eubalaena glacialis*).

The visually verified acoustic data set will be used to assess and validate a range of PAM density estimation methods for right whales. This approach could also improve the understanding of the sensitivity to variation in biological (age, sex, behavior), environmental (time of day, weather) and anthropogenic (ship noise) parameters.

The use of fixed-PAM for density estimation has the potential to increase the amount of density data in all U.S. waters and Navy ranges that can be used in the Navy's acoustic effects modeling.

The team will collect visual survey data concurrently with acoustic recordings of vocally active right whales using a time-synchronized fixed PAM array. Results will be used to validate range-specific detection probability, false positive rates and cue (or call) rates for estimating acoustic density. Visual data will be recorded from a land-based survey platform using a theodolite and a visual observation team. Whale presence can reliably be detected out to 8 kilometers (km), but the survey will be focused within a 3 km radius area from the survey platform. The visual observation team will detect, localize and track all right whale groups within that observation area.

Acoustic data will be collected using six underwater sound recorder units (Soundtrap 300 STD) arrayed over the 3km radius observation area. Three additional units will be added to the north, south and east of the visual observation area to determine if sounds come from outside or inside the visual detection area. For example, whales calling offshore will be detected first on the offshore unit, before detection on any of the recordings within the central array.

Additional field efforts to obtain estimates of cue rates to apply to the PAM density estimation approach will include acoustic animal-borne tag (DTAG-3) attachments on suitable weather days and focal follows and acoustic tracking of whales within the acoustic array. Density estimation will focus on two cue types (all calls and contact calls).

The effective detection area estimates will be explored through three approaches.

1. Spatial Capture Recapture (SCR)—This will be the primary approach for estimating the effective detection area. It relies on detecting at least some calls on multiple underwater sound recorders.
2. Extended SCR—In addition to hydrophone location, additional information such as received level and time of arrival will be used to make more accurate inferences.
3. Acoustic model-based assessment of effective detection area (EDA)—This will be based on published values for right whale call source levels and acoustic propagation modeling. The EDA estimates will be validated using visually tracked animals.

Southern right whales.
Israel Maciel, permit SISBIO 60324-2

Finally, the visually obtained density of right whales in the bay will be compared to the output of PAM density estimates to validate the approaches applied for estimation of right whale density using passive acoustic methods.

This validation work will allow scientists to better assess the application of different PAM density estimation approaches for right whales.

Field efforts will be initiated in 2020 and acoustic density estimations will begin in late 2020 as field data are available.

This study is focused on developing and validating a PAM survey design for acoustic density estimation of a right whale species with concurrent visual and acoustic localization of all right whales. The results of this validation work will allow scientists to better assess the application of different PAM density estimation approaches for right whales. These data will inform density estimation approaches for other right whale species, including the endangered North Atlantic right whale, by providing a better understanding of the variability in cue rates.

Shore-based observation.
Renata Sousa-Lima, Insituto Australis

The project will provide the raw acoustic and visual data, analyses of these data sets, peer-reviewed scientific publications and oral presentations at scientific meetings. At the completion of this study, visual survey data collected under the project will be contributed to the OBIS-SEAMAP online database and tag data to the Movebank data repository.

About the Principal Investigators

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

Len Thomas is Professor of Statistics and member of the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. He specializes in developing statistical methods to apply to ecological problems. Dr. Thomas has a Ph.D. in forestry from the University of British Columbia.

Key contributor: Graduate student Julia Dombroski, Syracuse University.

INVESTMENT AREA 3
MONITORING TECHNOLOGY DEMONSTRATIONS

LMR Investment Area 3 focuses on further development of technology to improve field data collection methods. Specific emphasis is given to utilizing existing Navy technologies and sensors for advancing environmental research and data collection. These technology investments enable efficient and cost-effective implementation of the Navy's MSM program in support of the Navy's environmental compliance and permitting processes.

These technology investments enable efficient and cost-effective implementation of the Navy's MSM program.

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

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

The following three projects—two ongoing and one new start—are summarized in this section. The ongoing projects are

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

The new start project is

1. Project 41—Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags.

Navy Counselor 1st Class Jorge Delgado

Ongoing Projects

Extended Duration Acoustic Tagging of Right Whales

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

NEED

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

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

PROJECT

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

This project is testing new suction cup materials with micro-texture for non-invasive tags on baleen whales to provide the longer sampling times needed to improve animal movement and behavioral response data collection. Attachment mechanisms employing biocompatible glues are also being evaluated. The testing within this study was the first to apply tags with the newly developed micro-texture suction cups to a free-ranging baleen whale.

New suction cup materials will help the longer-term recording tags remain on animals longer, extending behavioral response data collection.

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

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

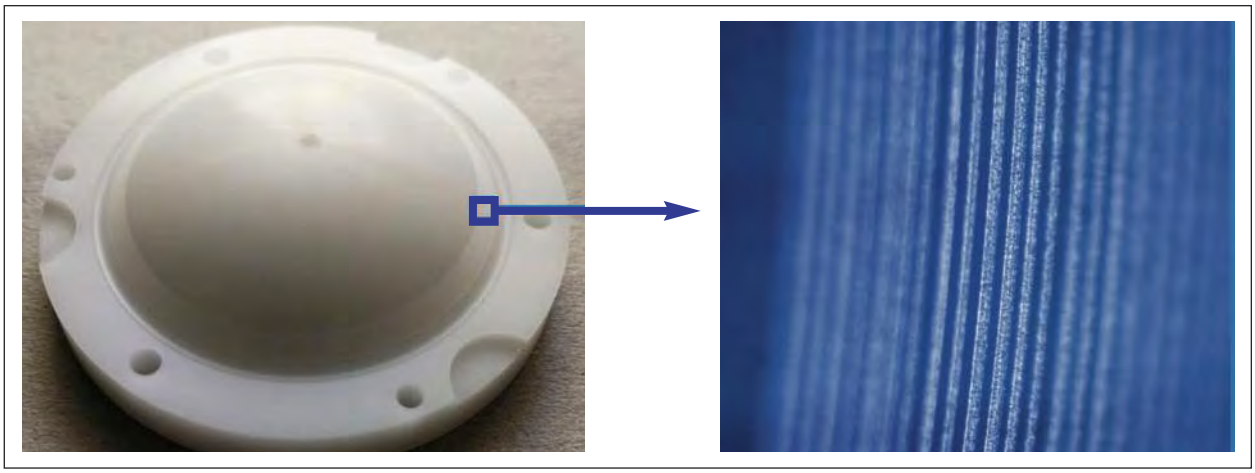
Testing during 2018 used two suction cup versions—a Shore 40A cup (standard D3 suction cup

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

material with micro-texture) and a slightly firmer Shore 60A cup. (A third version, the Shore 30A, that had been tested in 2017 was deemed too soft for general use.) These two suction cup versions were used for tagging during the June 2018 Stellwagen Bank National Marine Sanctuary humpback whale research program's field season. Analysis of tag data revealed that all tags ultimately detached due either to extended periods of whale breaching or to impacts with other whales and/or the bottom during foraging activities. The team also used the firmer Shore 60A cup while tagging Southern right whales as a part of a Marine Mammal Commission-funded field season in Brazil in August 2018.

Based on field results from both 2017 and 2018, the team modified suction cup configurations for 2019. While the Shore 60A material stiffness provided promising results for attachment times, there also was evidence of sliding prior to detachment. The team revisited potential benefits offered by the softer Shore 30A, including less sliding. A cup that combined the overall stiffness of the 60A with a softer lip using 30A material was developed. Over four deployments in June 2019, this combination provided attachment times ranging from 9.7 to 23.3 hours. While the average attachment duration between the stiffer Shore 60A and the combination cups were comparable, initial analyses suggest that each cup version appears to offer benefits related to an animal speed and skin condition. More analysis is underway.

In addition to suction cup materials and textures, the project is evaluating if biocompatible glues can safely offer additional attachment durations. Thus far, design and testing has focused on attachment, strength and release mechanisms using materials under laboratory conditions. Plans include field testing of the final design with both the micro-texture and adhesive suction cups in 2020.



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

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

Southern right whale.

About the Principal Investigators

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

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

High Fidelity Acoustic and Fine-scale Movement Tags

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

NEED

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

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

PROJECT

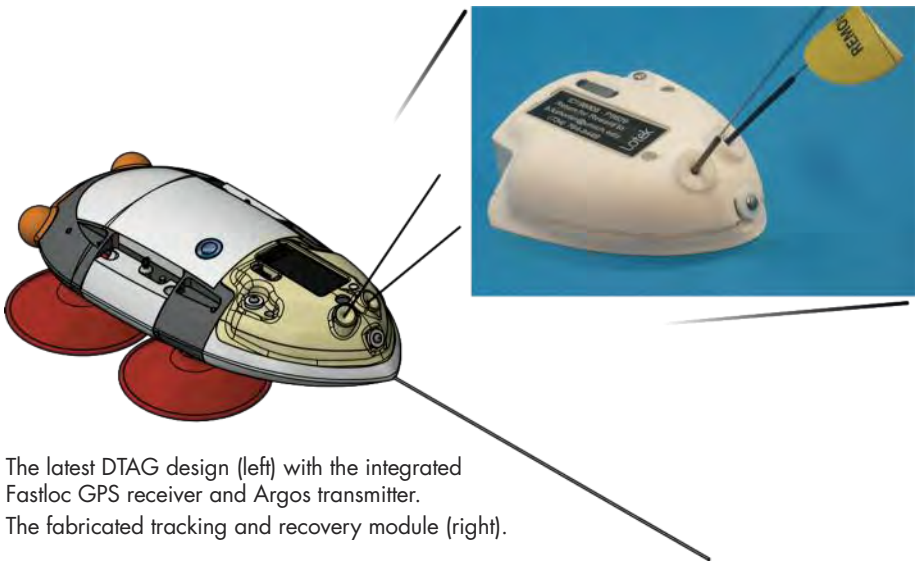
The DTAG is one type of acoustic tag often used in research and monitoring. DTAGs are highly integrated, compact, low-power, high-fidelity acoustic bio-logging tags that are well suited for studying both deep-diving beaked whales and large baleen whales. The combination of high-resolution acoustic and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

This project is focused on building a pool of new (third) generation DTAGs (DTAG-3s) to enhance availability of the instrument for behavioral response research. This work builds on the tags that were created with support from the ONR MMB program. Field-ready tags are leased to researchers on a monthly basis, with support and technical advice for the field effort provided as needed. The tag leasing program is an innovative aspect of the project that is making tags readily available and sustaining tag improvements. Following the completion of the fieldwork, tags are returned for inspection and testing. Feedback, coming from researchers using the tags under rigorous field conditions, is used to inform tag design for improved field reliability and performance. Importantly, the funds required to the maintain the tag pool, along with the costs associated with the design and fabrication of new field-ready tags, come directly from revenue generated by the pool. The project successfully produced and fielded the 20 pool tags from the original proposal, and has used the funds generated by the leasing to produce an additional 17 tags (37 total). The lease pool has been able to grow to meet the increasing needs of the researchers. The use of these tags by researchers in the field has increased every year since the project began in 2016, with 71 tag months supported in 2019. This is one-and-a-half times the usage from 2018 and seven times the amount the tags were used in 2016.

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

Another important aspect of the project has been improving the design and manufacturability of the tags. The tags now have a modular design that enables incremental adjustments, rather than requiring overall tag redesign. For example, the

connector used for data offload and recharge was upgraded during 2018, as was the integrated VHF transmitter. During 2019, tag antenna configurations continued to be tested to evaluate tradeoffs in increasing VHF tracking distances with changes to the tag design. In addition, beginning in 2019 and continuing into 2020, Fastloc GPS units will be added to 10 newly fabricated tags (see illustration). The team will also work on developing and testing algorithms to estimate the location of the animal using tag and GPS data.



The latest DTAG design (left) with the integrated Fastloc GPS receiver and Argos transmitter. The fabricated tracking and recovery module (right).

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

About the Principal Investigator

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

MC3 Drew Verbis

New Start Project

Improved Tag Attachment System for Remotely-deployed Medium-term Cetacean Tags

Principal Investigator: Russ Andrews
Project Status: New Start, Project 41

NEED

N-0203-19: Improvement of Medium-term Telemetry Tag Attachment Duration

The Navy requires data to support behavioral response criteria in its acoustic effects modeling. Animal telemetry (i.e., tagging) provides much of the needed marine mammal baseline behavioral data (diving, movement) and behavioral and physiological response to exposure from Navy sources. Longer tag attachment durations could offer improved data to better understand the duration and severity of behavioral responses to anthropogenic noise. The Navy is interested in research towards the re-design and/or improvement of medium-term tag attachment methods for dart-style tag attachments for marine mammals. Improved dart design is needed to increase tag deployment durations to an average of one to several months.

PROJECT

This demonstration project will build on previous ONR MMB-funded efforts and assess the feasibility of producing an alternative tag attachment element for remote tag deployment. The current attachment for the Low Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) tag system employs darts—small diameter metal shafts with externally facing barbs, or petals. A significant concern is how these rigid anchors interact with the surrounding tissue when the external part of the tag is subjected to large dynamic forces (including physical contact with other animals and the seafloor or breaking the water surface), which is a common occurrence for many tagged cetaceans. The project team is exploring attachment mechanisms that are

- More compatible with the animal's tissue
- Less susceptible to breakage
- Well balanced with the external tag electronics package
- Easily attached
- Able to remain attached for longer periods
- Designed to work with the current suite of LIMPET tags and Sound and Motion Recording and Transmitting (SMRT) tags.

Longer tag attachment durations could offer improved data to better understand the duration and severity of behavioral responses to anthropogenic noise.

The project is organized into four separate phases, with each subsequent phase determined by the outcome of the preceding one.

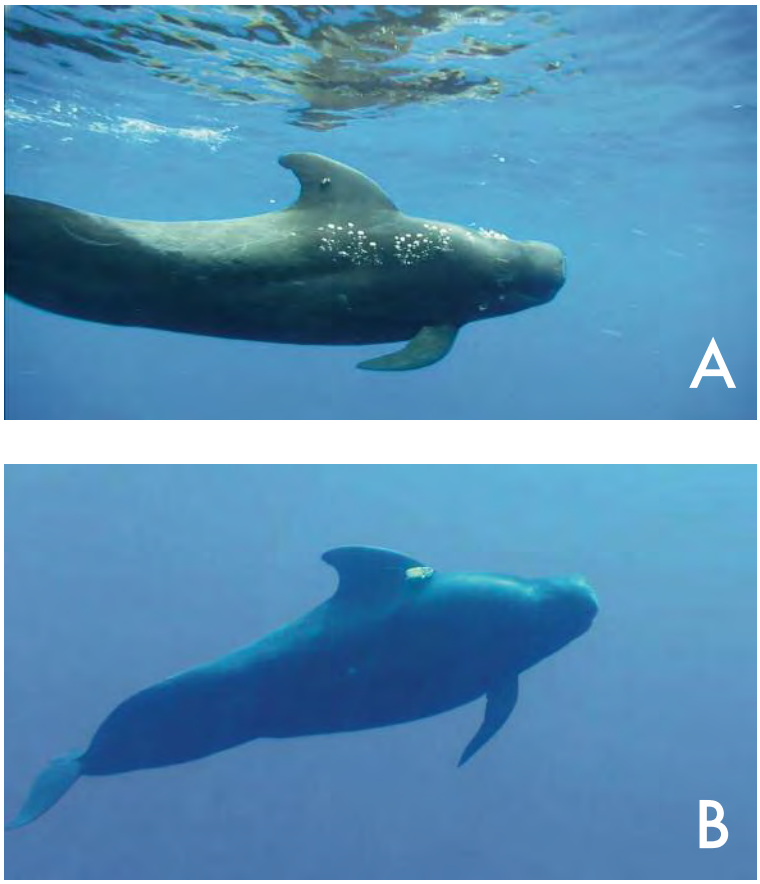
1. Phase 1—Refine two existing designs: 1) an elastic connection between a more tissue-friendly implanted anchor and existing LIMPET external package and 2) a single-point attachment, loosely tethered tag. The team will collaborate with mechanical and biomechanical engineers on computer-aided design (CAD) and finite-element analysis. After refinement in CAD, physical prototypes will be constructed using rapid-prototyping methods to identify appropriate designs for testing. Employing the

protocols previously developed for testing cetacean tag attachments—a static pull apparatus and a dynamic pendulum impact force tester—will be used to test prototype attachment elements under simulated implanted conditions. The attachment element prototypes will be tested concurrently with existing LIMPET barbed darts to compare retention ability and resistance to *in situ* breakage. The prototype elements will be implanted into both simulated cetacean tissue (e.g., fiber-reinforced rubber) and tissue retained from stranded cetacean carcasses.

2. Phase 2—Conduct field deployments of the most promising designs. Designs will be tested on two species (short-finned pilot whales in Hawaii, fin whales in Southern California or beaked whales off Guadalupe Island, depending on access). The appropriate designs and target species will be decided after Phase 1. The primary goal in these field tests will be to significantly reduce variation in attachment times.

3. Phase 3—Implement the lessons learned from field trials to improve the attachment element design(s). Demonstrate the final design in field trials with the same two species chosen for Phase 2. Prepare a final report on the field trials.

4. Phase 4—Conduct dedicated detailed follow-up studies to assess the condition of the previously tagged whales and demonstrate that the improved anchor design has not increased the negative effects of tagging. This will include quantifying wound healing and the effects of tagging on whale survival, reproduction and behavior. The team will use high-resolution digital photos, histological examination of biopsy samples and imaging from forward-looking infrared (FLIR) cameras to examine how well tag attachment sites are healing and to evaluate thermoregulatory function in the dorsal fin. The diving and movement behavior of tagged animals will also be evaluated.



Two of the types of tags that could benefit from improvements in the tag attachment systems are shown attached to short-finned pilot whales: A) LIMPET tag, B) SMRT tag.
Tagging conducted under research permits15330 and 20605

Phase 1 of the project is slated for completion in 2020. Depending on the decisions for subsequent phases, Phase 2 field deployments of initial designs will occur in 2021, Phase 3 deployment of final designs in 2022 and Phase 3 follow-up studies in 2023.

Improved attachment mechanisms that support recording the movements and behavior of cetaceans over longer periods of time, and more consistently, than is currently possible will improve the Navy's ability to monitor cetaceans before, during and after exposure to Navy sources. This will enable the Navy to develop behavioral response functions that are more closely aligned to the statutory definition of take for military readiness activities.

Improved attachment mechanisms will improve the Navy's ability to monitor cetaceans before, during and after exposure to Navy sources.

Project results will be presented at scientific conferences and submitted for publication in scientific journals. If successful, the improved tag anchor systems will be transitioned to the commercial market after completion of all functionality tests.

About the Principal Investigators

Russel Andrews, the lead principal investigator, is a senior scientist with the Foundation for Marine Ecology & Telemetry Research. His expertise includes marine mammals, diving behavior and physiology, and remote monitoring equipment and instrumentation. Dr. Andrews earned his Ph.D. in zoology at the University of British Columbia.

Greg Schorr, co-PI, is a research biologist at the Foundation for Marine Ecology & Telemetry Research. He has been studying marine mammals for 18 years with much of his research focused on telemetry studies and deploying a wide variety of tags. His most recent focus has been using remotely deployed satellite tags to study beaked whale ecology and behavioral responses to anthropogenic sources of sound. Greg earned his geology degree from Colorado College.

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

INVESTMENT AREA 4 STANDARDS AND METRICS

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

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

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

The three ongoing projects included in this section are

1. Project 18—Acoustic Metadata Management for Navy Fleet Operations
2. Project 28—Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems
3. Project 34—Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar.

No new projects were funded in 2019.

Blainville's beaked whale.
NOAA/NMFS

Ongoing Projects

Acoustic Metadata Management for Navy Fleet Operations

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

NEED

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

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

PROJECT

This project is focused on developing a reference database for Navy acoustic metadata management. The project enhanced the capabilities of the Tethys passive acoustic monitoring (PAM) metadata database.

Early funding from the ONR MMB and from Bureau of Ocean and Energy Management (BOEM) supported the project team's efforts to develop standardized data representations (schemata) describing instrumentation, effort, detections and localizations. This standardization within the Tethys database can be implemented on other systems (e.g., NOAA National Centers for Environmental Information [NCEI] acoustic archive) and is becoming a community standard. These schemata provided a solid foundation for developing an official standard.

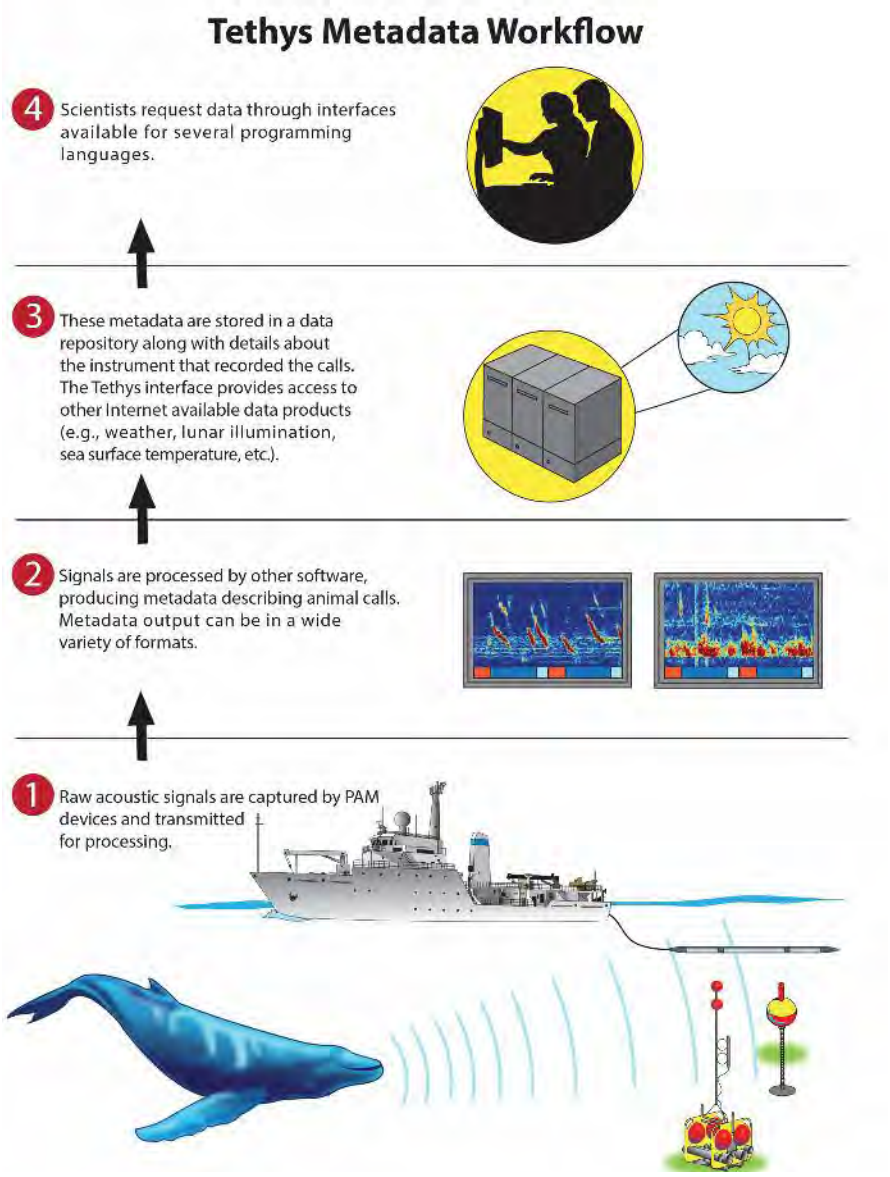
Subsequent funding from LMR and BOEM enabled improvements that have made Tethys more usable by the U.S. Navy, other federal agencies and the scientific community in general. Specific tasks have included providing additional data analysis and reporting facilities, identifying bottlenecks in performance as the existing databases continue to grow in size and further developing the program's schemata for localization. These efforts are improving the Navy's ability to perform long-term marine species monitoring data management.

> These provide a straightforward method for Navy analysts to make sophisticated data requests.

Recent project work focused on scalability and user friendliness. Tethys servers now manage decades of acoustic detection and localization effort with over 15 million entries on the most heavily used server. With researchers adding increasingly large sets of detection and localization data, the Tethys team implemented ways to reduce the amount of time needed to archive and query these results. These have decreased the archive and querying times by over a factor of three. Many design changes also address Tethys users' suggestions to make the interface more understandable and easier to use. Users noted that it is common to ask a series of similar questions, such as "Where was I looking for beaked whales?" and "Where did I find them?" With a new data-centric view, users can enter the information once and ask multiple questions without reentering data. Coupling this view with the ability to save frequently used questions, the user interface is easier to use.

Work with the Naval Information Warfare Center (NIWC) during 2019 focused on standardizing

localization data, an important feature for identifying an animal's location, not just its presence. The project team provided system training at NIWC and worked with staff on new developments. A number of other Tethys functional capabilities were expanded, including saving data from the Tethys web client to Matlab and R software packages. Together, these provide a straightforward method for Navy analysts to make sophisticated data requests and export the data into data analysis packages. These data can then be used to address Navy-relevant questions, including using the data as part of a species density estimation in an environmental compliance report. These new capabilities will be part of the next release in the second quarter of 2020.



Overall accomplishments to date have included faster processing of large data sets, improved user interface and standardizing and including localization data in the Tethys database. Work being continued under other funding will enable ongoing improvements.

The standards development process under the Acoustical Society of America (ASA) framework continued with work group meetings and draft products. Recent work has focused on ensuring that Navy range needs are met and many of the proposed standards changes have been incorporated into Tethys. This process will move the Tethys schemata towards an American National Standards Institute (ANSI) standard.

About the Principal Investigator

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

Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems

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

NEED

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

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

PROJECT

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

This project helps to support development of an ASA-sponsored ANSI standard on towed cabled

Towed hydrophone array.
Martijn van Riet

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

The standard will provide requirements and recommendations for six areas: Initial project planning, hardware, software, operator training, operating procedures and performance validation.

In 2017 a working group met at NOAA headquarters in Silver Springs, Maryland to review the draft standard report and map out routes forward. The outcome of the meeting was to create subcommittees to focus on different portions of the standard.

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

During 2018 and 2019 individual subcommittees focused on topics such as standardizing assumptions one can make about frequency content and source level of various marine mammal species and defining the basic training and documentation for PAM operators in the field. In 2019 the results of subcommittee efforts were translated into a formal standard format. A draft section on Project Planning has been completed, while draft sections on Hardware and Validation have been circulated to the broader working group for review. A complete draft standard is anticipated to be ready for voting by the Acoustical Society of America by Fall 2020.

Towed array.
D.M. Rossi, University of Pavia

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

About the Principal Investigator

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

Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar

Principal Investigators:
Elizabeth Henderson, Susan Jarvis
Project Status: Ongoing, Project 34

NEED

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

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

PROJECT

This project is taking a collaborative approach to develop a set of standardized detectors and classifiers, along with a set of standardized nomenclature for Navy sonar signals. The project team includes Navy investigators who are assessing the efficacy and broad applicability of existing sonar detectors, which are provided with support by non-Navy researchers. The group is working to ensure that the greater research and signal detection communities are involved in developing a standardized and generalizable sonar detector.

The project is pursuing six overall tasks, with project team member responsibilities carefully defined to protect classified information while working toward standardized non-classified methods.

An MH-60R Sea Hawk helicopter hovers with its sonar dipping buoy lowered.
MC3 Josue L. Escobosa

Guided-missile destroyer USS *Donald Cook* (DDG 75).
MC1 Kyle Steckler

1. Review literature for existing detectors/sonar signals descriptions.
2. Compile classified sonar data sets from Navy ranges.
3. Gather sonar detectors and non-classified sonar data from collaborators.
4. Run detectors on data sets.
5. Develop sonar detector/classifier (or suite of detectors if needed) based on results of comparison test.
6. Develop standardized nomenclature describing different signal types to be used by bioacoustics community.

Work during 2019 focused on the literature review, initiating work with collaborators, obtaining, testing and adjusting existing detectors, and obtaining non-Navy sonar data.

The literature review examined papers and reports with descriptions of sonar, including AN/SQS-53 hull mounted, DICASS sonobuoys and AN/AQS-22 dipping sonar. The effort highlighted characteristics such as frequencies, source levels, sonar components, duty cycle, bandwidth and others. It also included identifying descriptors used in the Navy's Acoustics Effects Model (NAEMO). This helped to identify issues regarding the detection and classification of sonar signals. The Navy sonar classification guidelines are informing how to select descriptive nomenclature. The review also identified sonar descriptions that are already in the public domain (e.g., within environmental impact statements or published papers).

Work to compile classified sonar data sets from Navy ranges revealed tasks that will be necessary to select and prepare data sets for use. This includes digitizing data, defining recording length and identifying data issues such as clipping, harmonics and noise.

Researchers from two organizations—Cornell Bioacoustics Research Program and Bio-Waves, Inc.—are working with the project, including sharing detectors and associated non-classified data sets for analysis. During 2019, the project ran available test data sets using Cornell's Raven-X detector, Bio-Waves SonarFinder, a generalized power-law (GPL) detection algorithm and the Silbido detector from San Diego State University and

the University of California San Diego. Initial results are helping to identify potential pitfalls in detector comparisons, data preparation steps that might be required prior to analyses and core characteristics that might be appropriate for a standardized detector.

This will promote comparable results from independent research on the effects of Navy training and testing activities, including Navy sonar, on marine life.

Work during 2020 will focus on more in-depth analyses of detector capability comparisons and applying detectors to more data sets. The Navy members of the team will continue to compile a standardized passive acoustic data set from Navy range data. The data set will include multiple examples of Navy sonar, such as hull-mounted sonar (e.g., AN/AQS-53C) operating in two different modes, helicopter-dipping sonar (e.g., AN/AQS-22) and an active sonobuoy sonar (e.g., AN/SSQ-62 DICASS). Working with multiple types of sonar sources will help to establish a benchmark of the necessary characteristics of broadly applicable sonar detectors. During the compilation and validation of Navy data sets with sonar, the Naval Undersea Warfare Center (NUWC) sonar warrant officer will be consulted to ensure that investigators know what the source properties of each sonar signal should be and that any nomenclature used is unclassified.

By the end of the project, the team plans to run all selected detectors on all data sets and compare results using standardized performance metrics. This will help to quantify and evaluate the performance of these existing detectors against known sources in multiple environments. Building on these results, the team will work to develop a new detector or set of detectors or to identify ways in which an existing detector can be adjusted to meet the need for a standardized detector. The end products will also include standardized, unclassified nomenclature for reporting.

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

About the Principal Investigators

Elizabeth Henderson is a bioacoustic scientist at the Naval Information Warfare Systems Center. Dr. Henderson earned her Ph.D. in biological oceanography and bioacoustics at the University of California San Diego. She focuses on marine mammal acoustic behavior and noise impact analyses for environmental compliance.

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

INVESTMENT AREA 5 EMERGENT TOPICS

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

The ongoing project summarized in this section is.

1. Project 35—Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources.

Ongoing Project

Multi-spaced Measurement of Underwater Sound Fields from Explosive Sources

Principal Investigator: Peter H. Dahl
Project Status: Ongoing, Project 35

NEED

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

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

PROJECT

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

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

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

There will be three far-field measurement sites, arranged to characterize propagation effects. These will be configured to provide data on

An explosive detonation.
MC2 Josh Bennett

effects of varying depths and distances from the explosive source. Each site will be equipped with VLAs to collect site-specific data, which will encompass varying depths (up to 1,000 meters), thermocline influences and overall acoustic field. The equipment also will collect essential environmental data, such as water sound speed and surface wave spectra, needed for the modeling and interpretation of the observations of acoustic propagation.

During 2019 the team procured necessary equipment and tested tourmaline and Sound Trap sensors that will be used in field measurements. In addition, work focused on coordination with Navy personnel conducting explosive training and determining which types of events would be most appropriate to conduct field measurements. Based on range schedules, the first field test is planned for late 2020.

The data collected directly apply to improving the accuracy and verification of NAEMO-based predictions of underwater sound fields from explosives at both close and long ranges. This is critical to improving the Navy's analysis of the effects of explosive sources on marine species.

About the Principal Investigator

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

Key collaborator: Altan Turgot, Naval Research Laboratory.

Partnerships

The LMR program often works with other organizations on projects that offer benefits to Navy needs. Such partnerships help to leverage funding, expand demonstration and validation options, and draw on additional expertise.

Two partnerships are summarized in this section. The ongoing partnership is

1. The Sonobuoy Liaison Working Group.

The new start partnership is

1. The Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life.

Ongoing Partnership

Sonobuoy Liaison Working Group

LMR continues to participate in and keep members of the Sonobuoy Liaison Working Group (SLWG) informed on the sonobuoy allocation for marine mammal research. LMR is responsible for determining which priority research projects receive available sonobuoys. For 2019, 480 sonobuoys were available, all of which have been allocated.

Projects and organizations receiving sonobuoys are listed in the following table. These sonobuoys are playing a significant role in expanding our data sets, and thus knowledge, related to where animals occur and when they are present.

Project	Organization
North Atlantic right whale shipboard and aerial surveys	NOAA Northeast Fisheries Science Center
Gulf of Mexico Bryde's whale surveys	NOAA National Marine Service Southeast
NOAA Pacific Marine Environmental Laboratory surveys	NOAA Marine Mammal Laboratory/ Alaska Fisheries Science Center
Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS)	NOAA Pacific Islands Fisheries Science Center
California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys	University of California at San Diego/Scripps Institution of Oceanography

An MH-60R Sea Hawk helicopter launches a sonobuoy.
MC Seaman Dylan M. Kinee

New Start Partnership

The Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life

The Subcommittee on Ocean Science and Technology (SOST) Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML) partnership moved to a new level during 2019 when three projects were jointly selected and funded by five participating agencies.

Operating under the auspices of the National Science and Technology Council's Committee on the Environment, Natural Resources, and Sustainability (CENRS), the SOST advises CENRS on national issues of ocean science and technology and serves as the lead interagency entity for federal coordination on those matters. The SOST ITF-ONML was then organized to increase coordination and communication across federal agencies in addressing issues related to the potential impacts of anthropogenic noise on marine life.

Five participants partnered to jointly fund research on the auditory capabilities of mysticete whales.

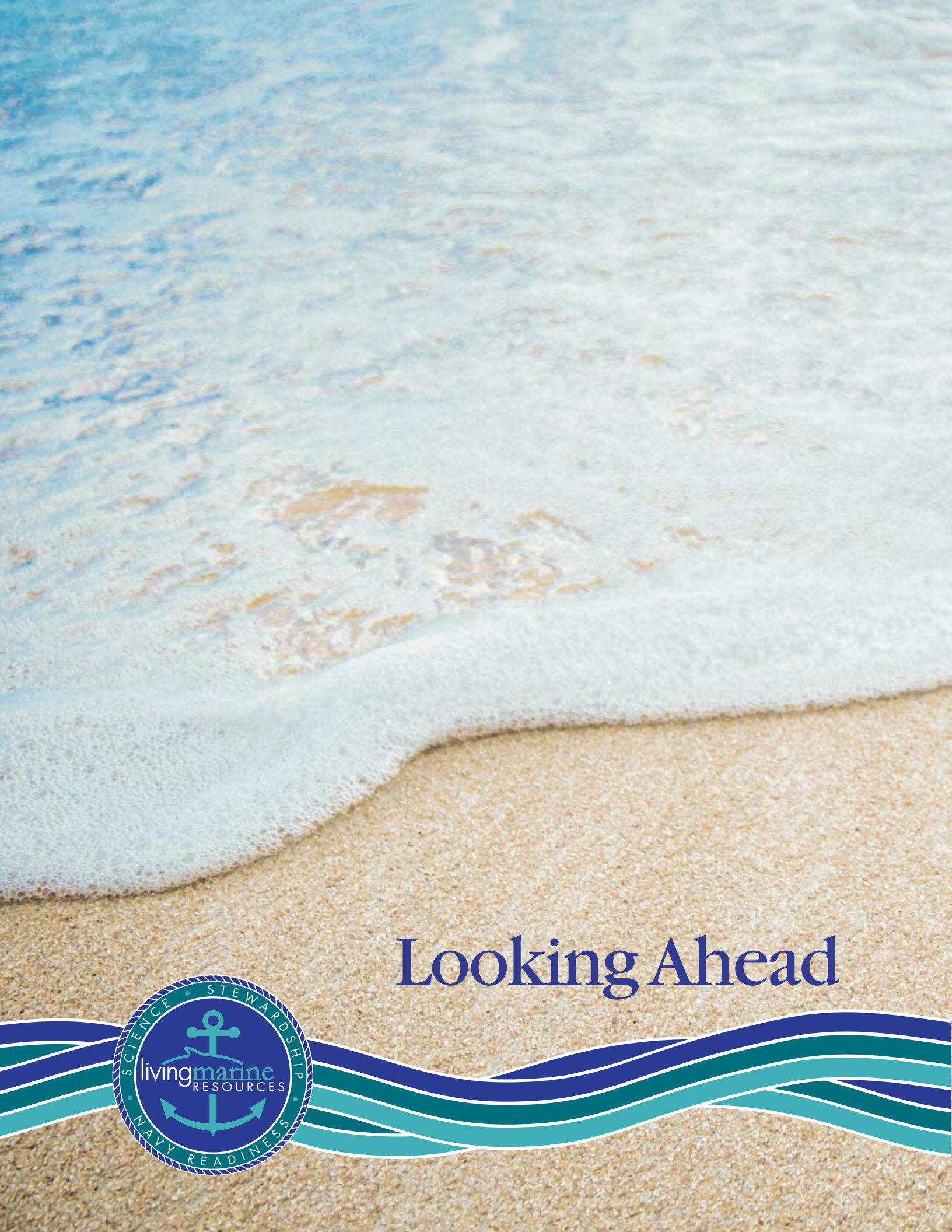
Five of the SOST ITF-ONML participants—the Chief of Naval Operations Energy and Environment Readiness Division, Office of Naval Research, the Bureau of Ocean Energy Management, the National Oceanic and Atmospheric Administration, and the Marine Mammal Commission—partnered to jointly fund research on the auditory capabilities of mysticete whales. The group issued a call for proposals, via the LMR program, in July 2018 pertaining to development of audiograms for mysticetes. Following careful review and discussion by

Gray whale.
Dr. Steven Swartz, NOAA

members of the review committee, three projects that covered a variety of methods were funded to increase the chance of success in obtaining data to address the need topic. The three projects are

1. Collection of AEP Hearing Thresholds in Minke Whales
2. Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds
3. Investigating Bone-conduction as a Pathway for Mysticete Hearing.

Two of the three projects—Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales, and Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds—are being managed by the LMR program. Summaries of these two are presented in this report on page 59 and 61, respectively. The third project—Investigating Bone-conduction as a Pathway for Mysticete Hearing—is being managed by ONR MMB. Fact sheets for each of these three projects are available on the LMR website, www.navfac.navy.mil/LMR, under the SOST Partnership tab.



Looking Ahead

We envision an exciting and bright future for the support LMR provides to the Navy. In 2020 we look forward to seeing many additional publications, results, methods and technologies from LMR-funded research transition into application within the Navy's environmental compliance process. Several LMR projects will be completed in 2020 and become available for transition or further investigation.

LMR anticipates funding a few additional projects from our Fiscal Year 2020 (FY20) proposal solicitation. These new projects may include studies pertaining to multiple need topics, including marine mammal acoustic software application enhancements, conditioned reduction of hearing sensitivity and frequency-dependent temporary threshold shift in California sea lions. These studies will be initiated in FY20 to ensure that results and methods will be available in time to be incorporated into the Navy's next environmental compliance cycle.

Looking beyond 2020, LMR will continue to invest in tools, technologies and methods that will enable us to collect marine species data and investigate critical questions about the effects of Navy training and testing activities. The oceanic environment is a challenging and expensive place to study. Many of the tools and technologies needed to assist the Navy's Marine Species Monitoring program in meeting monitoring requirements in a cost-effective manner are not readily available. These tools and technologies will be necessary to sustain at-sea training and testing in response to environmental permit requirements.

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

We remain optimistic about the program's future because of the great scientists and engineers who work with us.

An important challenge we all are facing in 2020 is the effect of the COVID-19 pandemic. As we write this, we still are in the early stages of determining what work can, and cannot, be conducted during this time. Field work planned for late winter and early spring has been delayed, which will influence many of the original project timelines. Nevertheless, our six years of managing this program have taught us to be ready to adapt and address new challenges, including one like this. Despite the many uncertainties of this time, we remain optimistic about the program's future because of the great scientists and engineers who work with us. They are no strangers to addressing unexpected events in the field and finding new ways to accomplish their tasks. We all will adapt to ensure that we are fulfilling our mission to support the Navy with priority research needs during these difficult times.

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

LMR Publications

Included here is a list of publications that became available in 2019 and that were partially or fully funded by the LMR program. These publications are of great value to the Navy's at-sea environmental compliance process and directly feed into the NEPA, MMPA, and ESA compliance documentation.

For a list of publications from prior years, please see the previous LMR program reports, available at our website—www.navfac.navy.mil/lmr.

Baumgartner, M.F., Bonnell, J., Van Parijs, S.M., Corkeron, P.J., Hotchkin, C., Ball, K., Pelletier, L.P., Partan, J., Peters, D., Kemp, J., Pietro, J., Newhall, K., Stokes, A., Cole, T.V.N., Quintana, E. and Kraus, S.D. (2019). Persistent near real time passive acoustic monitoring for baleen whales from a moored buoy: System description and evaluation. *Methods in Ecology and Evolution*, 10(9): 1476–1489. (DOI: 10.1111/2041-210X.13244)

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Friedlaender, A.S., Bowers, M.T., Cade, D., Hazen, E.L., Stimpert, A.K., Allen, A.N., Calambokidis, J., Fahlbusch, J., Segrem, P., Visser, F., Southall, B.L. and Goldbogen, J.A. (2019). The advantages of diving deep: Fin whales quadruple their energy intake when targeting deep krill patches. *Functional Ecology*, 00: 1–10. (DOI: 10.1111/1365-2435.13471)

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Kastelein, R.A., Helder-Hoek, L. and Gransier, R. (2019). Frequency of greatest temporary threshold shift in harbor seals (*Phoca vitulina*) depends on the fatiguing sound level. *The Journal of the Acoustical Society of America*, 145(3): 1353–1362. (DOI: 10.1121/1.5092608)

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Kastelein, R. A., Helder-Hoek, L., Cornelisse, S., Huijser, L.A.E., & Gransier, R. (2019). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth-octave noise band at 32 kHz. *Aquatic Mammals*, 45(5): 549-562. (DOI: 10.1578/AM.45.5.2019.549).

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*Keen, E.M., Scales, K.L., Rone, B.K., Hazen, E.L., Falcone, E.A. and Schorr, G.S. (2019). Night and day: Diel differences in ship strike risk for fin whales (*Balaenoptera physalus*) in the California Current system. *Frontiers in Marine Science*, 6: 730. (DOI: 10.3389/fmars.2019.00730)

Miller, D. L., Glennie, R., Seaton, A. E. (2019). Understanding the stochastic partial differential equation approach to smoothing. *Journal of Agricultural, Biological, and Environmental Statistics*, 25: 1–16. (DOI: 10.1007/s13253-019-00377-z)

For a list of publications from prior years, please see previous LMR program reports at www.navfac.navy.mil/lmr.

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**These publications were not specifically funded by the LMR program, but acknowledged use of data, methodology or technology developed with funding from the LMR program.*

MC2 Patrick Semales

Acronyms and Abbreviations

3S3.....Sea mammals, Sonar, Safety project phase 3
ABR.....Auditory brainstem response
AEP.....Auditory evoked potentials
ANSI.....American National Standards Institute
ASA.....Acoustical Society of America
ASCR.....Acoustic spatial capture recapture
ASSR.....Auditory steady-state response
ATA.....Advanced Technology Attachment
AUTEC.....Atlantic Undersea Test and Evaluation Center
AUV.....Autonomous Undersea Vehicles
BAA.....Broad Agency Announcement
BOEM.....Bureau of Ocean Energy Management
BREVE.....Behavioral Response Evaluations Employing robust baselines and actual Navy training
BRS.....Behavioral Response Study
BUMED.....Bureau of Medicine and Surgery
CAD.....Computer-aided design
CAS.....Continuously active sonar
CEE.....Controlled exposure experiment
CREEM.....Centre for Research into Ecological and Environmental Modelling
CSEE.....Coordinated sonar exposure experiments
CT.....Computerized tomography
DCLT.....Detection, classification, localization, and tracking
DECAF-TEA.....Density Estimation for Cetaceans from Acoustic Fixed Sensors in Testing and Evaluation Areas
DET.....Detection error trade-off
DICASS.....Directional command activated sonobuoy system
DIFAR.....Directional low-frequency analysis and recording
DMON.....Digital acoustic monitoring instrument
DSP.....Digital signal processor/processing
DTAG.....Digital acoustic recording tag
EDA.....Effective detection area
EIS.....Environmental Impact Statement
ESA.....Endangered Species Act
ESTCP.....Defense Environmental Security Technology Certification Program
GIS.....Geographical information system
GPL.....Generalized Power Law
GPS.....Global positioning system
HMM.....Hidden Markov model
IACUC.....Institutional Animal Care and Use Committee
ICI.....Inter-click interval
ICMP.....Integrated Comprehensive Monitoring Plan
IPR.....In-progress Review
ISO.....International Organization for Standardization
kHz.....kilohertz
LF.....Low frequency
LFDCS.....Low-frequency detection and classification system
LIMPET.....Low Impact Minimally Percutaneous External-electronics Transmitter
LMR.....Living Marine Resources
LMRAC.....Living Marine Resources Advisory Committee
MFAS.....Mid-frequency active sonar
MHT.....Multi-Hypothesis Tracker
MMC.....Marine Mammal Commission
MMPA.....Marine Mammal Protection Act
MSDD.....Marine Species Density Data
MSM.....U.S. Navy Marine Species Monitoring Program
NAEMO.....Navy Acoustic Effect Model
NEPA.....National Environmental Policy Act
NAVAIR.....Naval Air Systems Command
NAVFAC EXWC.....Naval Facilities Engineering and Expeditionary Warfare Center
NAVO/NAVOCEANO.....Naval Oceanographic Office
NEFSC.....Northeast Fisheries Science Center (NOAA)
NIWC.....Naval Information Warfare Center
NMFS.....National Marine Fisheries Service
NMMF.....National Marine Mammal Foundation
NOAA.....National Oceanic and Atmospheric Administration
OE.....Opportunistic exposure
ONR.....Office of Naval Research
ONR MMB.....Office of Naval Research Marine Mammal Biology
OPNAV N45.....Chief of Naval Operations Energy and Environmental Readiness Division
PADN.....Portable Acoustic Data Node
PAM.....Passive acoustic monitoring
PAM-DE.....PAM-based density estimation
PAS.....Pulsed active sonar
PCoD.....Population consequences of disturbance
PI.....Principal investigator
PMRF.....Pacific Missile Range Facility
PTS.....Permanent threshold shift
RHIB.....Rigid hulled inflatable boat
RDT&E.....Research, development, test and evaluation
ROC.....Receiver-operator curves
SBIR.....Small Business Innovative Research
SCC.....Submarine Command Course
SCORE.....Southern California Offshore Range
SCR.....Spatial Capture Recapture
SEL.....Sound exposure levels
SLWG.....Sonobuoy Liaison Working Group
SOCAL.....Southern California
SOST ITF-ONML.....Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life
SPL.....Sound pressure levels
TRC.....Technical Review Committee
TTS.....Temporary threshold shift
TWS.....Traveling wave speed
VLA.....Vertical line array
WHOI.....Woods Hole Oceanographic Institution
µCT.....Computed microtomography

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