LMR

U.S. NAVY'S LIVING MARINE RESOURCES PROGRAM

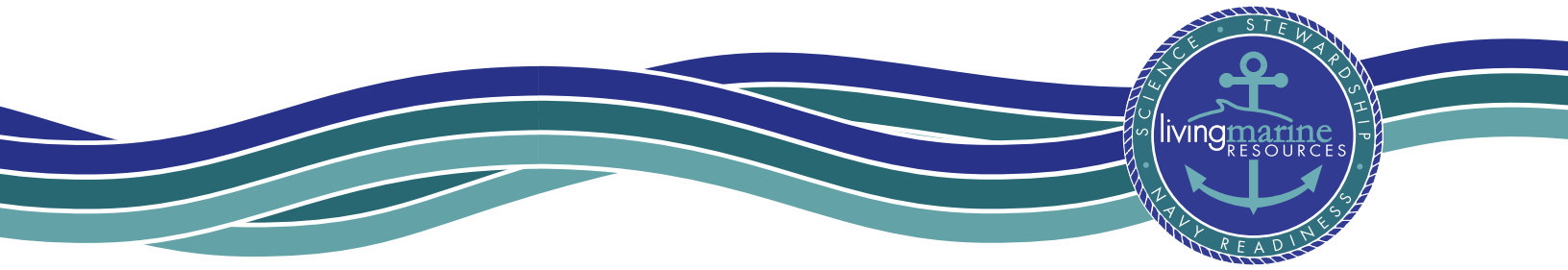
2020

STATUS REPORT

JUNE 2021

LMR 2020

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



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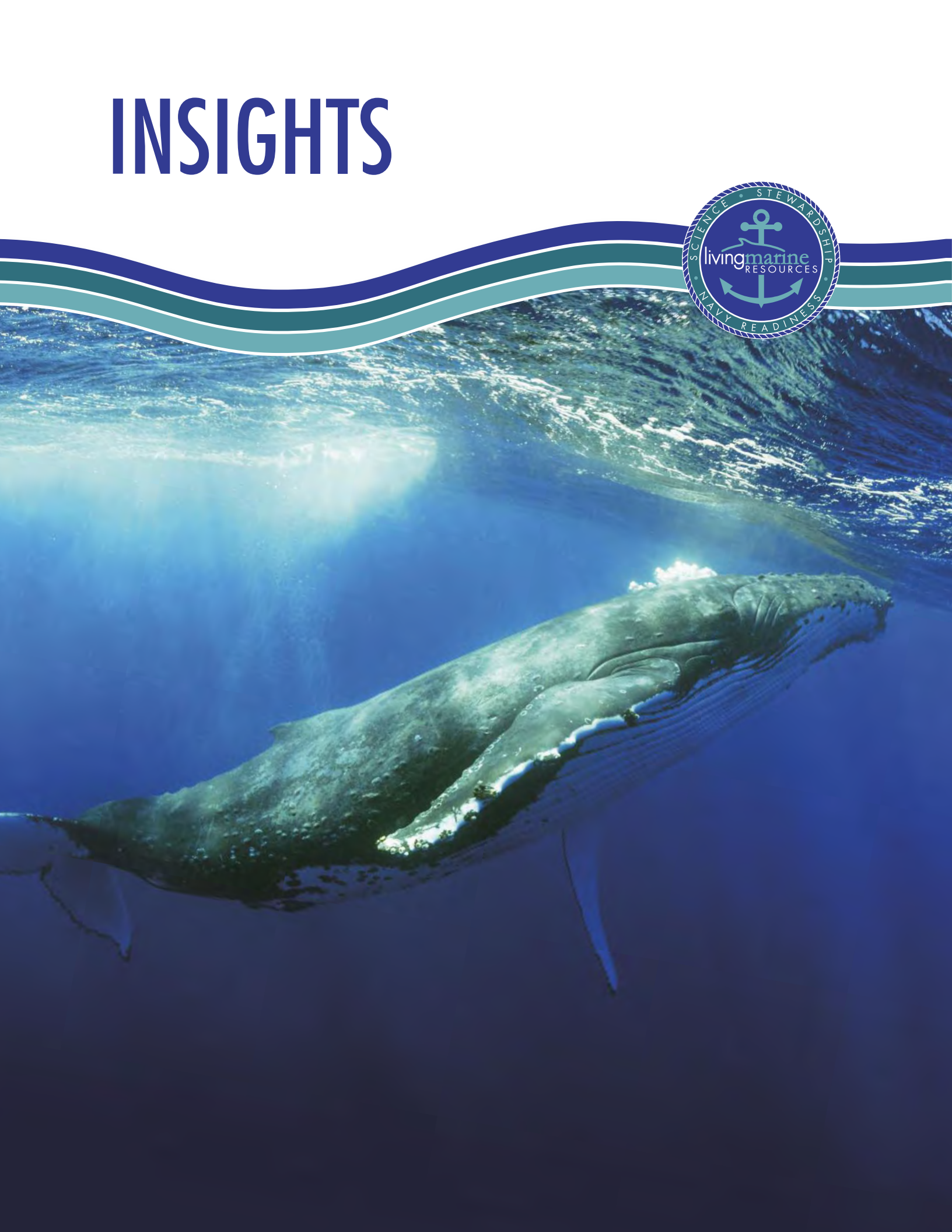
Marine mammal photos that do not include a credit/permit number are from stock photo services. Most headshots are by photographer Kenny Backer, Oxnard, CA.

INSIGHTS


SCIENCE • STEWARDSHIP
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RESOURCES
NAVY READINESS

We are excited to share with you the 2020 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 10) to learn more about how the LMR program supports the Navy's at-sea environmental compliance process.

The LMR program was managing 27 projects during 2020, all carefully selected to meet specific Navy-defined needs and provide additional scientific credibility to the Navy's environmental compliance analysis. Of the 27 projects, we initiated two new projects and had 21 ongoing. Four were completed during 2020 and are being transitioned to the end users.

Anu Kumar
Program Manager

Mandy Shoemaker
Deputy Program Manager

We are proud of the project scientists' accomplishments and their continued determination to fulfill LMR's mission to address priority research needs.

In 2020 LMR resourcefully addressed COVID-19 pandemic-induced obstacles. Many of the projects with delayed field efforts shifted focus to analysis and publications, mitigating the potentially negative effects on progress toward research goals. Maintaining progress in 2020 was a significant achievement in itself. We are proud of the project scientists' accomplishments and their continued determination to fulfill LMR's mission to address priority research needs.

This year we continued to broaden collaboration with other research programs. First, we maintained our 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 interest in mysticete hearing to invest in research projects (page 18). Next, we submitted a research topic through the Naval Postgraduate School's (NPS's) Naval Research Program to evaluate the performance of directional sensors in detecting and tracking sounds produced by marine mammals. A project was awarded to NPS, and if successful, will provide guidance on sensor configuration for future monitoring technologies. In a third 2020 effort, the Small Business Innovation Research (SBIR) program awarded LMR a Phase 1 Option technology development project (page 18). This project is focused on expanding the technical capabilities of unoccupied underwater vehicles (UUV) to detect marine mammals in waters difficult to reach and survey. If successful, this will allow the Navy's monitoring program to extend their reach and survey larger areas in a cost-effective manner.

We also want to share highlights from one of our completed projects to provide a sense of the scope of our work. One of these, TTS in Harbor Seals Due to Fatiguing Sound of Several Frequencies (Project 33, page 30), obtained critical data

on the impact to harbor seal hearing related to Navy sonar signals. These data help us to develop a more robust scientific basis for estimating the effects of Navy training and testing on harbor seal hearing. By the close of 2020, this project has produced five publications, with one more forthcoming in 2021. These publications provide Navy planners with the information needed to refine the criteria and thresholds used to estimate effects for broad range of frequencies from multiple sonar types, ensuring future naval sonar systems.

For information on our many other projects, which cover a wide range of Navy needs—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 Portfolio section (beginning on page 22).

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.

Our downloadable publication list, updated quartlerly, provides Navy environmental planners with the latest science coming from LMR-funded research.

Nineteen publications and technical reports, resulting directly from LMR-supported projects or using data from LMR projects, were published in 2020, with several more to be released in 2021.

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To promote access to these publications, we have added a downloadable publication list to our public website. This list, updated quarterly, provides Navy environmental planners with the latest science coming from LMR-funded research.

> The program continues to be relevant and foundational to the current and future Navy mission because of your involvement.

We encourage you, through this report and our other communication channels, to learn more about the unique ways in which 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 progam.

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

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.

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.

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 11.) Thus in 2012, OPNAV N45 transitioned the funding line and formally designated the LMR program as the 6.4 applied research, development, test and evaluation (RDT&E) program, and restructured it to address the Navy's at-sea environmental compliance needs. While OPNAV N45 remained the resource sponsor, controlling the budget and final approval authority, the program needed dedicated management. A program office and manager were established at the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) in Port Hueneme, California. This location allowed the program to manage and focus the increasing number of research needs, solicit and evaluate proposals, award contracts and provide end users the results they need.

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

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

NAVY READINESS DEPENDS ON ENVIRONMENTAL COMPLIANCE

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

As part of the regulatory compliance process associated with these Acts, the Navy is responsible for assessing the potential impacts from military readiness activities. The Navy is required to apply for environmental permits to conduct activities that may result in impacts to protected species regulated under environmental statues such as ESA or MMPA.

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

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

> Environmental compliance is fundamental to continued uninterrupted training and testing, and ultimately, to Navy readiness.

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 (ONR MMB) program
2. The LMR program
3. The U.S. Navy Marine Species Monitoring (MSM) program.

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 14).

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 and exploratory and developmental technological solutions, which help to advance the state of the science. These projects can often have high technical risk and long timelines.

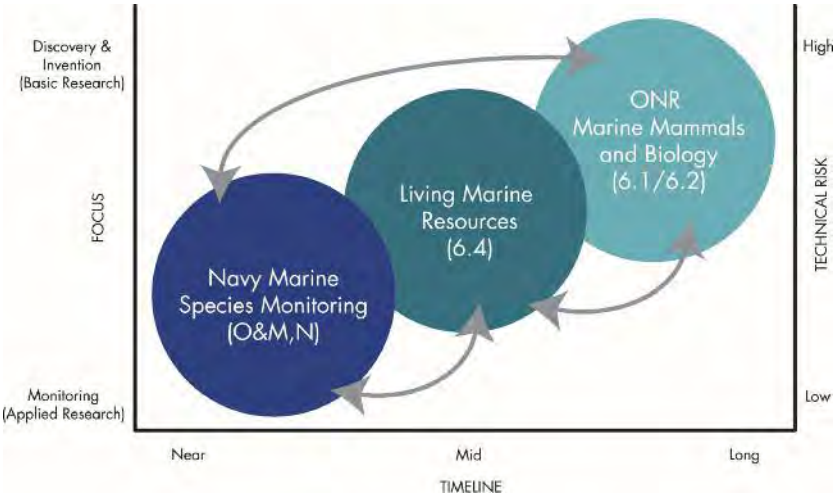
Outcomes from this program are often transitioned to the LMR program to continue to develop, demonstrate and validate solutions, and then link products directly to an end user need. In some cases, outcomes can be transitioned directly to the Navy MSM program if ready for integration.

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.

As the chart above 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. See the accompanying case study, *Keeping Tag Technology Evolving*, for one example of a technology's evolution.

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.

KEEPING TAG TECHNOLOGY EVOLVING

Animal monitoring tags are relatively small but valuable tools to collect the data the Navy needs to know more about the marine species that are present near at-sea training and testing activities. Tag data inform environmental compliance monitoring, critical to keeping at-sea ranges open. The Navy's three marine species programs—Office of Naval Research's Marine Mammal Biology program (ONR MMB), the Living Marine Resources (LMR) program and the Marine Species Monitoring (MSM) program— have steadily pushed monitoring tag technology forward. The evolution of the digital acoustic monitoring tag (DTAG) to its recent version (DTAG-3+) exemplifies the benefit of this cooperative effort.

In the early 1990s, the ONR Physiology and Marine Mammal Biology program (an ONR MMB predecessor) funded researchers to increase both tag sensor capabilities and lifespan. While many tag advancements were successful, incorporating acoustic recording capabilities into a compact, animal-borne package posed some technological challenges. To help address the challenges, the Strategic Environmental Research and Development Program (SERDP) and ONR co-funded a project to add acoustic capabilities. Researchers incorporated both a hydrophone for recording sounds and other sensors that could record animal movements. This new acoustic version, the DTAG, was first used in 1999. By 2002, the DTAG was upgraded to include four hydrophone channels and 16 gigabytes of memory, a significant improvement over the 400 megabytes possible in the first version. This new iteration, DTAG-2, also added new sensors that provided more detailed data on an animal's movement, including a tri-axial accelerometer, a magnetometer and pressure and temperature sensors.

The combination of high-resolution acoustic and movement sensors made these tags key enabling technology for behavioral response research. LMR stepped in to demonstrate and validate this promising technology. Some of the early LMR projects, particularly the Southern California Behavioral Response Study, successfully demonstrated the data collection benefits but also the production drawbacks to the existing device. It highlighted a need for a more streamlined production process to lower the cost and increase availability.

In 2016, the LMR program funded two new projects—Project 27, High Fidelity Acoustic and Fine-scale Movement Tags and Project 21, Extended Duration Acoustic Tagging of Right Whales—to help create a better process for producing the new DTAGs and to improve how the tags attached to the animal. Project 27 was initially tasked with building 20 DTAGs to have tags more readily available. The project team also initiated an innovative tag lease program, which sustains tag production and continuing improvements in tag design. The tags are leased to researchers on a monthly basis, with support and technical advice for the field effort provided as needed. When fieldwork is completed, tags are returned for inspection and testing. The researchers—who have used the tags under rigorous field conditions—provide feedback, which is used to inform design improvements for field reliability and performance. Project 21 created and tested new material combinations for the tag suction cups. The latest combinations and design are keeping the tags attached longer, enabling data collection over longer periods. The additional data collected during longer deployments are providing new insights into behaviors.

These tags are now being implemented by field teams supporting the Navy's Marine Species Monitoring program. Based on the continued feedback, the project team has added sensors in the tag package while reducing mass and volume by 30 percent. This new version, the DTAG-3+, includes Fastloc® GPS and Argos capabilities.

From research to field testing to implementation, the coordination among the Navy's three marine species programs has contributed to advancements in an important tool for the Navy's environmental compliance efforts, helping to keep at-sea training ranges operating.

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 and the Technical Review Committee—as described below.

LMR Advisory Committee

The LMR Advisory Committee (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

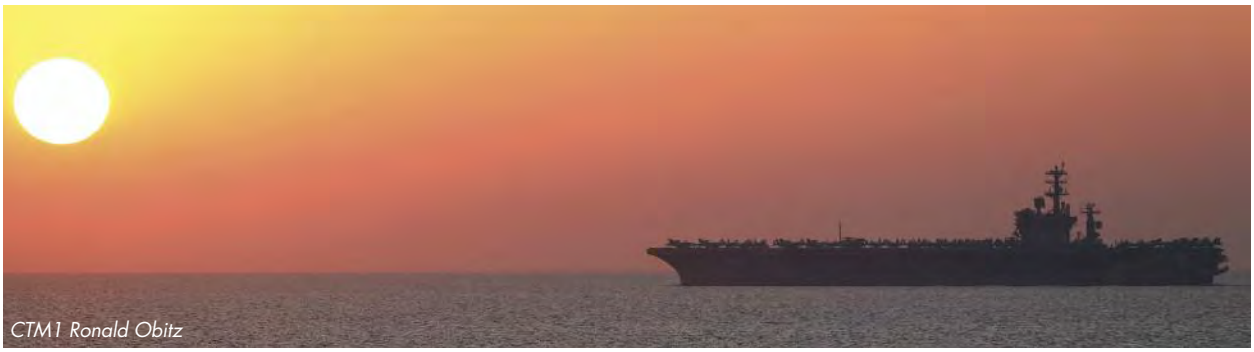
The purpose of the technical review committee (TRC) is to serve as an expert panel to review proposals and provide feedback to the Navy regarding technical sufficiency. Based on the need topics for which the Navy solicits proposals, the TRC membership may change to ensure the committee possesses the 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.



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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.

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

2. Data processing and analysis tools

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

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

> The projects funded by the program are carefully selected to achieve the program's mission.

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 MSM program to


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support the Navy's environmental compliance and permitting processes.

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

4. Standards and metrics

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

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

5. Emergent topics

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

Navy Needs

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

- Address research challenges faced by the Navy at-sea environmental compliance community to provide solutions that will reduce operational constraints.
- Identify an existing gap in knowledge, technology and/or capability in order to provide flexibility to the Navy to achieve the mission.
- Fulfill 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 Portfolio section of the report.

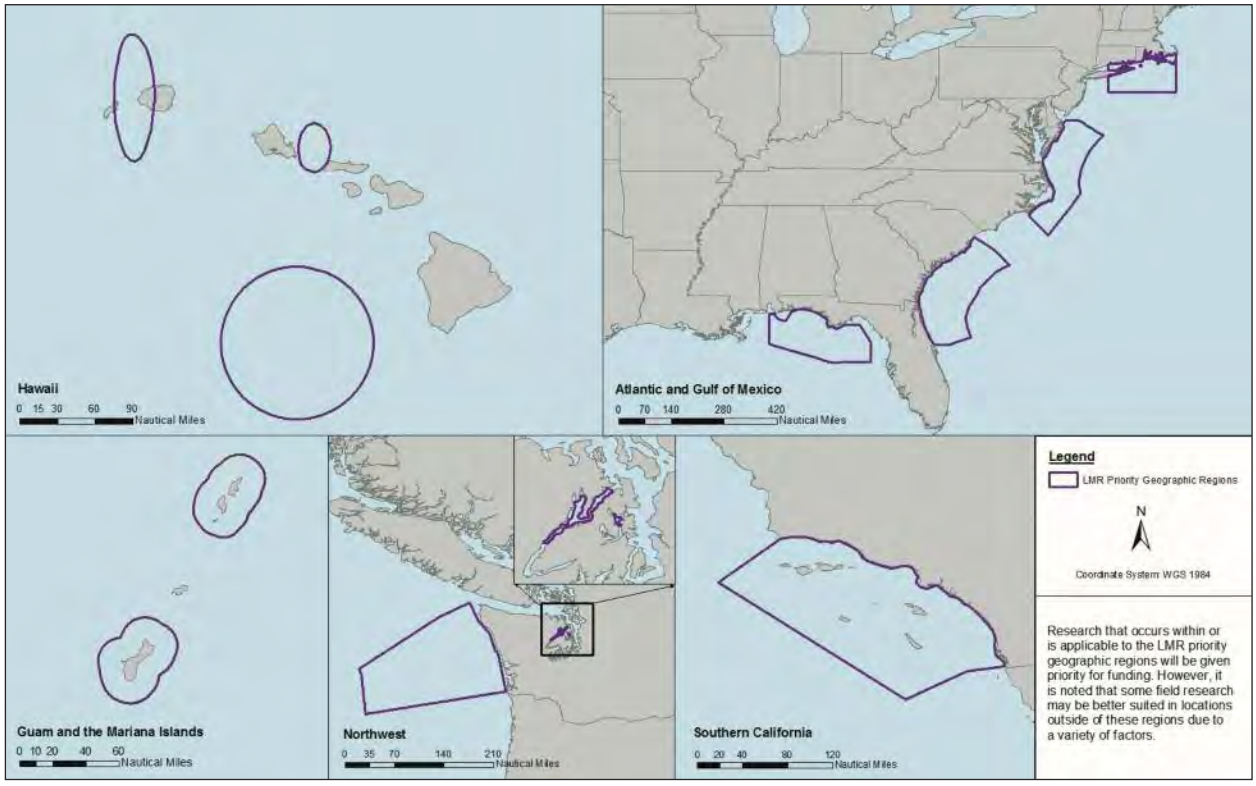
Priority Species and Geographic Regions

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 (beaked whales, sperm 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.



LMR priority geographic 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 Innovation 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.

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

An example of multi-agency coordination is LMR's active support to the Subcommittee on Ocean Science and Technology (SOST). 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 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' Behavioral Response Thresholds, are summarized on pages 53 and 55, respectively.

The LMR program is also expanding partnerships with industry through the SBIR program, which provides an opportunity for domestic small businesses to engage in federal research and development that has the potential for commercialization. The research topic submitted by LMR, Unoccupied Underwater Vehicle (UUV) Technology to Enable Readiness of Navy Ranges, seeks technologies that can collect a broad spectrum of ocean acoustic data to support large scale spatial and temporal research on ambient and biological sources of sound. The following three companies participated in Phase I:

1. Triton Systems
2. OASIS
3. EOM Offshore.

After the completion of Phase I, Triton Systems was selected for a Phase I option. At the end of the Phase I option, Triton will submit a proposal for Phase II, which if selected will begin in Summer 2021.


MC2 Taylor DiMartino

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 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 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.

Research Publications Spreadsheet

During 2020, the LMR program added a full listing of program research publications, in spreadsheet format, to the LMR website. At the close of 2020, the spreadsheet list included 113 publications, beginning in 2013 from the earlier Marine Mammal Research program, which preceded the LMR program's establishment in 2014. While the list focuses on publications resulting from Navy LMR funding, it also includes publications not specifically funded by the LMR program but that acknowledged use of data, methodology or technology developed with funding from LMR.

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

The spreadsheet provides full citations (authors, year, title, journal, issue, etc.) and, as appropriate, the LMR project number and investment area under which it was funded. In addition to journal publications, the spreadsheet includes entries for final and technical reports.

The spreadsheet is updated quarterly. To see the spreadsheet go to www.navfac.navy.mil/lmr and click on the Publications tab.

Project Highlights Fact Sheets

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

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

In-progress Review

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

LMR Website

The program website (www.navfac.navy.mil/lmr) serves as a centralized repository for public information about the program. The site offers ready access to the newsletter, research publications list, 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.

PORTFOLIO

Completed Projects

Four projects were completed during 2020 and are summarized in this section. Results from these projects are now available for use by the Marine Species Monitoring program and those involved in environmental compliance.

The four completed LMR projects are

1. Project 17—Blue and Fin Whale Density Estimation in Southern California Offshore Range Using PAM Data
2. Project 18—Acoustic Metadata Management for Navy Fleet Operations
3. Project 28—Proposed ASA Standards on Towed Passive Acoustic Monitoring and Mitigation Systems
4. Project 33—TTS in Harbor Seals Due to Fatiguing Sound of Several Frequencies.

LMR Projects

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

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

NEED

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

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

PROJECT

This project worked 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. Such methods could help to provide data necessary for the Navy's acoustic impact assessments.

> This project allowed LMR to move one step closer to the ultimate goal of density estimation.

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 leveraged results from work completed under Office of Naval Research Marine Mammal Biology (ONR MMB) funding, using long-term passive acoustic data sets from SOCAL and acoustic tag data from the SOCAL Behavioral Response Study and other tagging studies in the area. In addition, this project included data collected using tags with medium-duration attachments. The team deployed a total of nine medium-duration tags (two blue whales and seven fin whales) as part of this project. Data from these multi-day tag deployments provided more information on variations between nighttime and daytime behaviors influencing calls.

In order to determine an animal's average call rate, the team first looked at potential biases in the tag data. They investigated whether tag attachment, animal sex, dive behavior, time of day, month or year affect the likelihood that a call is recorded on the tag. All of the blue whale A, B and D calls on the tags were detected and classified by an analyst. To identify which calls were attributed to the tagged animal, they developed a method based on relative root mean square values using a hierarchical approach that prioritizes calls occurring close in time over those occurring over an entire deployment. This allowed for cue rate determination per individual using acoustic tags without accelerometer data.

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

The team completed transition of the acoustic propagation models and probability of detection models for both blue and fin whales. The team also developed the first detection-classification

Fin whale.
Ana Širović

Blue whale.
Ana Širović

algorithm for efficiently extracting blue whale D calls and fin whale 40 Hz calls, both believed to be social calls used during foraging. These call types were chosen because they are produced by both sexes, which reduces the potential for sex bias in the analysis. The project team also explored sources of variability in cue rate and assessed how that variability affects density estimates potentially produced by the methods developed as part of this project.

This project allowed LMR to move one step closer to the ultimate goal of density estimation. The results include cue rate models for blue whale B and D calls (including evaluation of bias in the tag data) and automated detection methods for fin whale 40 Hz calls and blue whale D calls to facilitate density estimation. The project also added medium-duration tag data for improved cue rate estimation. Project results helped the LMR program identify the challenges with the methods of density estimation from passive acoustic monitoring and highlighted the priority for future investment to make this approach possible. This led to the investment in the ACCURATE project (page 72), which is further investigating the cue rate and stability in multiple species of marine mammals. Data from this project will be an important contribution to the ACCURATE 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; Goldie Phillips, University of California at San Diego; Jeppe Rasmussen, TAMUG; Tyler Helble, Naval Information Warfare Center.

Acoustic Metadata Management for Navy Fleet Operations

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

NEED

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

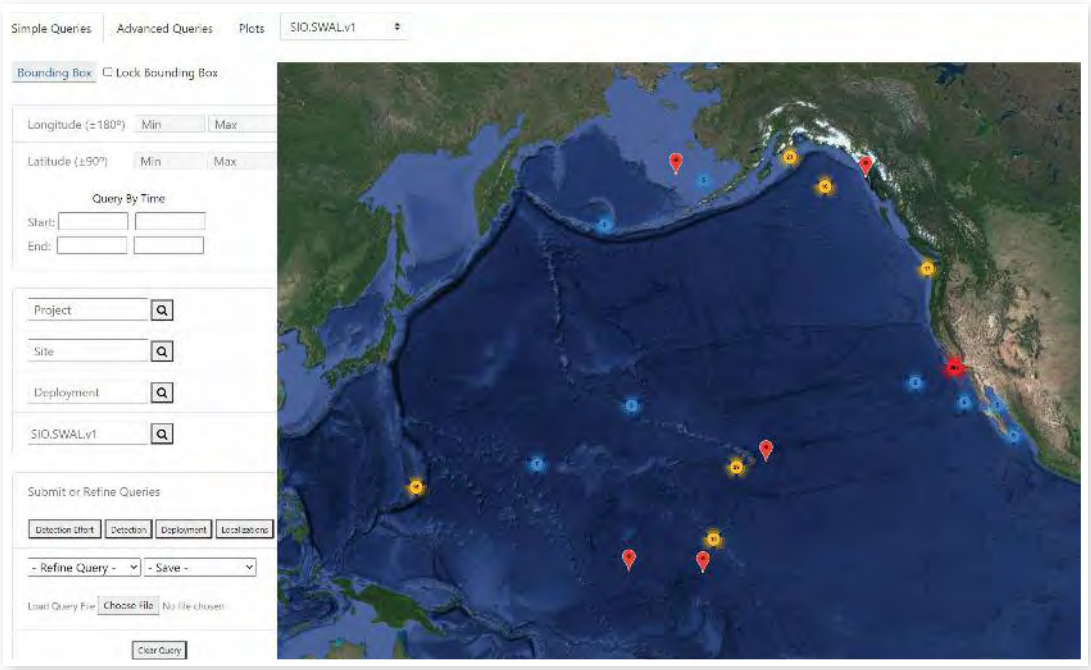
Current Navy-funded marine biological resource surveys span a variety of survey protocols and produce geo-referenced data products that frequently cannot be used together due to a lack of established standards. Data protocols, formats, standards and quality assurance procedures (QA/QC) are all items 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 focused on widening the usability of the community standards defined for preserving data related to passive acoustic monitoring and enhancing 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.

Funding from LMR and BOEM, as part of this project, enabled improvements that have made Tethys more usable by the U.S. Navy, other federal agencies and the scientific community in general. Specific tasks 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



The simple queries interface allows users to search for information based on criteria such as time, location, or specific criteria such as efforts to find a species. Results are shown on an interactive map and a searchable result tree (not reproduced here). Shown are 737 acoustic data logger deployments by the Marine Bioacoustics Research Collaborative with nearly 250 years of recording effort. Deployments that are close to one another are clustered into a single label that expands when the user zooms into the region.

localization. These efforts are improving the Navy's ability to perform long-term marine species monitoring data management.

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 has implemented ways to reduce the amount of time needed to archive and query these results. These have improved query response 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.

During 2019, the project team worked with the Naval Information Warfare Center (NIWC) to standardize localization data, an important feature for identifying an animal's location, not just its presence. The 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 were included in the latest version, 2.5, released in 2020. This release also reflects another round of optimization, resulting in up to one order of magnitude improvements in speed for some types of queries.

The standards development process under the Acoustical Society of America (ASA) framework continued with work group meetings and draft products. Recent work 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.

Overall accomplishments of this project have included faster processing of large data sets, improved user interface and standardizing and including localization data in the Tethys database. Version 2.5 is the tenth software release. The Tethys server includes capability for web, MATLAB®, Python, R and Java clients. Documentation for these clients is available. Products are freely available via the website https://tethys.sdsu.edu

This project's final report was submitted to the LMR program. A newly funded project—Project 46 Capability Enhancements for Tethys, a Passive Acoustic Metadata Workbench (page 95)—will be addressing ongoing improvements identified as part of this project.

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: Completed, 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 partnered in an effort to develop a standard for towed cabled PAM.

This project supported development of an ASA-sponsored ANSI standard on towed cabled PAM

Towed hydrophone array.
Martijn van Riet

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

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 addresses requirements and recommendations for initial planning, hardware, software, training, real-time mitigation and monitoring procedures and performance validation.

The standard provides 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 Spring, 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.

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 the subcommittee efforts were translated into a formal standard format. A draft section on Project Planning was completed, while draft sections on Hardware and Validation were undergoing review.

A complete draft standard was completed in June 2020, but due to COVID-19 the Acoustical Society of America has not voted on the standard. Hopefully this will occur in 2021.

Developing a standard for towed cabled PAM by a professional society creates 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 addresses 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.

TTS in Harbor Seals Due to Fatiguing Sound of Several Frequencies

Principal Investigator: Ron Kastelein
Project Status: Completed, 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 focused on TTS and hearing recovery in harbor seals to derive auditory weighting functions for seals. Harbor seals are appropriate subjects for multiple reasons. They have a wide distribution in the coastal waters of 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 up to a certain distance. In addition, while susceptibility to TTS has been shown to be frequency-dependent in bottlenose dolphins (*Tursiops truncatus*) and harbor porpoises (*Phocoena phocoena*), it has not been clear how sounds of different frequencies

Harbor seal.
Rani van de Vlist

Harbor seal.
Rani van de Vlist

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 focused on determining

1. The susceptibility to TTS of harbor seals over their entire hearing range
2. TTS onset derived from the 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. 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. The recovery rate of hearing after the fatiguing sound stops.

The project worked with two harbor seals that had been trained for research and had participated almost daily in psychophysical acoustic research for 14 years. During a hearing test, the trained harbor seals waited at a listening station, at a specific distance from the underwater loudspeaker. When they heard a sound, they would leave the station and swim towards the trainer for a reward. Each TTS session included 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 were conducted for each hearing test frequency. Initial exposure duration was one hour per session. Each fatiguing sound was produced at around five sound pressure levels (SPL). This approach provided insight into the relationship between TTS and SPL. Two or generally 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 (generally four times).

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, it was determined that testing

of these frequencies was not necessary since tests at 0.5 and 1.0 kHz required exposures of two, four and six hours to produce small TTSs.

This project produced five publications that report on TTS after seven frequency exposures: 0.5, 1, 2, 6.5, 16, 32 and 40 kHz. The project team found that harbor seal hearing is less susceptible to TTS due to low-frequency sound and more susceptible to TTS due to high-frequency sound, than formerly believed. The citations are listed below and are included in the spreadsheet at the Publications tab on the LMR website.

> The resulting data will be used to define the hearing weighting function and underwater TTS/PTS sound exposure level threshold values.

The resulting data will be used to define the Navy Phase IV hearing weighting function and underwater TTS/PTS sound exposure level 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 on seals.

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).

Publications through 2020

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.

Kastelein, R.A., Helder-Hoek, L., Cornelisse, S., Huijser, L.A.E. and Terhune, J.M. (2019). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 16 kHz. *The Journal of the Acoustical Society of America*, 146(5):3113–3122. DOI: 10.1121/1.5130385.

Kastelein, R.A., Helder-Hoek, L., Cornelisse, S.A., Huijser, L.A.E. and Terhune, J.M. (2020). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 32 kHz. *The Journal of the Acoustical Society of America*, 147(3):1885–1896. DOI: 10.1121/10.0000889.

Kastelein, R.A., Parlog, C., Helder-Hoek, L., Cornelisse, S.A., Huijser, L.A.E. and Terhune, J.M. (2020). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 40 kHz. *The Journal of the Acoustical Society of America*, 147(3):1966–1976. DOI: 10.1121/10.0000908.

Kastelein, R.A., Helder-Hoek, L., Cornelisse, S.A., Defillet, L.N., Huijser, L.A.E. and Terhune, J.M. (2020). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to one-sixth-octave noise bands centered at 0.5, 1, and 2 kHz. *The Journal of the Acoustical Society of America*, 148(6):3873–3885. DOI: 10.1121/10.0002781.

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 and 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 11 ongoing projects and one new project started in 2020. Note that one of the projects listed here, "Collection of AEP Hearing Thresholds in Minke Whales," was unable to start during 2020 due to COVID-19 restrictions. The original summary for that project is here for reference.

The 11 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 37—Collection of AEP Hearing Thresholds in Minke Whales. (SOST)
9. Project 38—Towards a Mysticete Audiogram Using Humpback Whales' Behavioral Response Thresholds (SOST)
10. Project 39—Use of "Chirp" Stimuli for Non-invasive, Low-frequency Measurement of Marine Mammal Auditory Evoked Potentials
11. Project 40—Temporary Threshold Shifts in Underwater Hearing Sensitivity in Freshwater and Marine Turtles.

The new start project is

1. Project 45—Frequency-dependent Underwater TTS in California Sea Lions.

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

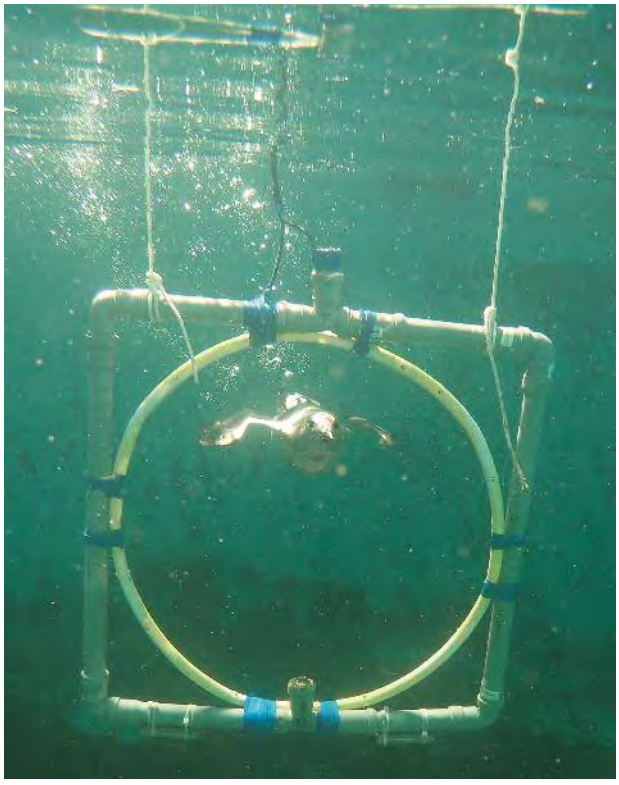
N-0103-16: Marine Species Hearing Research Related to the Acoustic Effects Criteria

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.

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

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.



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

This project is defining the hearing of up to three Auk species—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. 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.

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 add field-collected in-air AEPs on common murres in northwestern Iceland and marbled murrelets in Alaska in 2020. During 2018 and 2019, the team also continued in-air behavioral hearing training with a common murre. Preliminary measurements and thresholds were initiated and the team worked to improve false detection rates.

The team collected underwater behavioral hearing data during 2018 and 2019. The first set of underwater trials revealed that these birds do hear underwater, which previously was unknown. In 2019, training of one of the common murres was initiated for a more controlled test: to swim through an underwater hoop, which would trigger a sound, then to swim to the appropriate target based on whether or not it detected the sound. The test includes sounds across a range of frequencies. This work is building a behavioral audiogram of an Auk species.

Other work during 2019 included data analyses, manuscript preparation and publication, and anatomical scans. Two publications from 2019 included one detailing methods for collecting AEPs in the field and another on potential noise

Marbled murrelet.

impacts on puffins. Twenty-four anatomical scans in 2019 brought the total number of scans to 39. The highest quality samples were from Atlantic puffins (*Fratercula arctica*), for which the team conducted sound exposure modeling on the reconstructed hearing structures. By modeling a simulated sound source, the team can estimate pressure distribution across the ear canal at different frequencies to predict the most sensitive frequency. These results will ultimately be applied to marbled murrelet anatomical scans.

The team can estimate pressure distribution across the ear canal at different frequencies to predict the most sensitive frequency.

Plans for 2020 were affected by COVID-19 travel and work restrictions. Field-based in-air AEP measurements in Iceland and Alaska were postponed until 2021. Underwater behavioral audiogram training and testing work was slower than expected because of variable work schedules, as well as seasonal behavioral changes among the birds. The project team did push ahead with training and testing within the limitations. They also continued data analyses and had two manuscripts published during the year (see sidebar for citations).

Work planned for 2021 includes field-based AEPs measurements of non-endangered marbled murrelets in Alaska and of common murres in Iceland. Additional in-air and underwater behavioral audiogram testing will be conducted, and anatomical modeling will be continued through detailed measures of the auditory structures, comparative analyses, and working toward a manuscript for publication.

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 and Kirstin A. Hansen, University of Southern Denmark.

2020 publications

Hansen, K.A., Hernandez, A., Mooney, T.A., Rasmussen, M.H., Sørensen, K., and Wahlberg, M. (2020). The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. *The Journal of the Acoustical Society of America*, 147(6):4069. DOI: 10.1121/10.0001400.

Mooney, T.A., Smith, A.B., Larsen, O.N., Hansen, K.A., Rasmussen, M. (2020). A field study of auditory sensitivity in the Atlantic puffin, *Fratercula arctica*. *Journal of Experimental Biology*, 223. DOI: 10.1242/jeb.228270.

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.

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

The MarEcoTel team deploys a SMRT tag on a Cuvier's beaked whale on SOAR as part of a study to understand behavioral responses to mid-frequency active sonar.
Brenda K. Rone, MarEcoTel, permit 20465

SMRT tag being deployed on a fin whale in Southern California.
Gregory S. Schorr, MarEcoTel, permit 21163

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 related 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 productive field efforts, deploying three integrated, medium-term archival tags on Cuvier's beaked whales. The tags successfully collected opportunistic exposure data. 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 and sound and motion recording and telemetry (SMRT) tags were deployed. The Lander2 tags capture movement and location data, but no acoustic data. The SMRT tags record acoustics, depth, speed and GPS location, which are important for analyzing fine-scale behavior of the animal. Seven of the whales tagged in 2019 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 both the Naval Postgraduate School and Navy Acoustic Effect Model (NAEMO) analysts to model animal movement and sonar received level estimates from the

2018 tag data. An added data analysis effort during 2019 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.

> 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.

A SMRT tag was deployed on a Cuvier's in early January 2020, before bad weather ended the trip early. Additional tag deployments that were planned for 2020 were canceled due to COVID-19 travel and work restrictions. The team productively redirected efforts to conduct more detailed data analyses. While the original plan included a basic acoustic audit of SMRT tag data to capture animal sounds (e.g., click start/end times) and sonar pings, a more detailed audit added differentiating tagged versus conspecific clicks, buzz identification, impulsive events and more. The analyses are helping to advance cue rate assessments and to address some basic biology questions for Cuvier's beaked whales. The team also progressed on accurately identifying foraging dives without acoustic data. Efforts to identify suitable cetacean response models for processing extensive, multi-sourced data sets moved ahead earlier than planned.

Field efforts to tag Cuvier's beaked whales, and possibly fin whales, are planned for 2021. Data processing and analyses will continue, and manuscripts will be completed for publication.

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 more than 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: Stephanie Watwood, Karin Dolan, and the entire M3R team from the Naval Undersea Warfare Center; Stacy DeRuiter, Calvin University; Brenda Rone, Russ Andrews, David Sweeney, Shannon Coates 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

Bottlenose dolphin.

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.

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

The methodology includes measuring the hearing thresholds in bottlenose dolphins using both behavioral audiometric methods and electrophysiological AEP methods. Researchers establish baseline hearing thresholds, then measure hearing thresholds immediately before and after exposure to a fatiguing noise to determine any threshold shift occurrences. Subject health, welfare and behavior are continuously monitored and managed by attending veterinarians and animal care staff at the 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 included 54 control sessions and 21 one-hour exposure sessions at exposure levels of approximately 139 to 165 decibels (dB) sound pressure level, equivalent to approximately 175 to 201 dB sound exposure level. 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. A manuscript discussing auditory brainstem response in these dolphins was published in *The Journal of the Acoustical Society of America* in 2019.

Data collection was delayed due to COVID-19 restrictions; however, the low- and mid-frequency TTS testing was completed in 2020. During these exposures the dolphins were equipped with digital acoustic recording tags (DTAGs) to support received level estimates. Post-testing hearing (recovery) was also characterized. The team then worked to reconcile sound field/video analysis results and DTAG recordings to correct received exposure level estimates. Data analyses and manuscript preparation that had been planned for 2020 will be completed in 2021.

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

> The results will be immediately useful within the Navy environmental compliance process when quantifying potential explosive impacts to fish.

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.

Deploying fish cages off of San Diego. *Keith Jenkins*


Mackerel.

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.

Work during 2020 focused on analyzing 2019 mackerel data. Initial analyses suggest different outcomes between the sardines from 2018 and the mackerel, despite similar test conditions. Factors contributing to these differences could include different acoustic propagation conditions between trial years and morphological differences between the two species.

The first project manuscript was published in 2020 (see sidebar for citation). A second manuscript focusing on results of the mackerel field tests is in preparation, as is a third publication that includes observations of changes in inner ear hair cell distribution as result of exposure.

Original project plans for conducting a third round of trials in 2020, possibly with a third species, were delayed due to COVID-19 restrictions. The third field season is now planned for 2021.

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.

2020 publication

Dahl, P.H., Jenkins, A.K., Casper, B., Kotecki, S.E., Bowman, V., Boerger, C., Dall'Osto, D.R., Babina, M.A. and Popper, A.N. (2020). Physical effects of sound exposure from underwater explosions on Pacific sardines (*Sardinops sagax*). *The Journal of the Acoustical Society of America*, 147(4):2383. DOI: 10.1121/10.0001064.

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 pertaining to a sound source can influence behavioral response to sonar including sonar source level, source frequency, duty cycle (the ratio of transmission time to repetition time) and the effect of distance between the source 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).

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

Royal Norwegian Navy frigate KNM *Otto Sverdrup*.
The towed operational sonar is visible at the aft of the frigate.
CDR René Dekeling, RNLN


Sperm whale.

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 long-finned pilot whales (*Globicephala melas*).

The project has employed controlled (sonar) exposure experiments (CEE) using operational sonar sources from a research vessel and from a Norwegian frigate. The research team uses visual observers and acoustic arrays to locate whales of interest, and determines whether they meet the requirements outlined within the experimental protocol. 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 are being 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 sonar source (Socrates) from the research vessel. 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 was published in *Journal of Experimental Biology* in 2020 (see sidebar).

The 2019 field work, conducted from mid-August to mid-September, included CEEs using both the previously used scaled 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-DTAGs (recording sound, movement, location and diving depth) and conducted CEEs using PAS at different levels and ranges using the operational source on the Norwegian Navy frigate. Using the scaled source, the team completed additional CEEs mimicking the operational source transmission scheme. Overall, the team deployed 24 tags and conducted 11 CEEs.

> 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.

During 2020 the project team continued analyzing data collected during 2019. Work proceeded more slowly than expected due to COVID-19 travel and workplace restrictions. The final technical data report originally scheduled for 2020 is now planned for 2021. Remaining manuscripts will be completed during 2021.

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.

2020 publication

Isojunno, S., Wensveen, P.J., Lam, F-P.A., Kvadsheim, P.H., von Benda-Beckmann, A.M., Martín López, L.M., Kleivane, L., Siegal, E.M. and Miller, P.J.O. (2020). When the noise goes on: received sound energy predicts sperm whale responses to both intermittent and continuous navy sonar. *Journal of Experimental Biology*, 223(7): jeb219741. DOI: 10.1242/jeb.219741.

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 37), 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.

Physalus approaches a fin whale to conduct observations during a behavioral response study.
Annie Douglas, Cascadia Research Collective, permit 540-1811

Test scenarios for two sonar platforms: helicopter dipping and DICASS sonobuoys

	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.

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

The tagging team from Project 23 deploys the high-resolution, behavior recording tags 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, 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 provide for a precise source location and depth, which combined with the Fastloc® GPS locations from the tagged whale, make this data set ideal for conducting this type of test.

Additional CSEEs planned during 2020 were canceled due to COVID-19 travel and work restrictions. The team productively pivoted its focus to detailed data analyses and evaluating received level modeling options. The received level models from the Naval Postgraduate School (NPS) and from the Navy Acoustics Effects Model (NAEMO) were compared. Based on the analysis conducted, the team has decided to move forward with the NAEMO for estimating received levels for the non-acoustic tags.

During 2021, the team plans to complete the CSEEs, in coordination with tag deployment field


Cuvier's beaked whale.

efforts, depending on helicopter availability. Data processing and analyses will continue, and the full data set with exposures will be evaluated through the selected model framework.

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. Data will be assessed on both the long-term (foraging interruption) and short-term (order of seconds to minutes) to assess the full spectrum of responses. 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: Karin Dolan and Nancy DiMarzio, NUWC; Greg Schorr, Erin Falcone, Brenda Rone, Russ Andrews, David Sweeney and Shannon Coates, Foundation for Marine Ecology & Telemetry Research (MarEcoTel); Stacy DeRuiter, Calvin University.

Behavioral Assessment of Auditory Sensitivity in Hawaiian Monk Seals

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

NEED

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

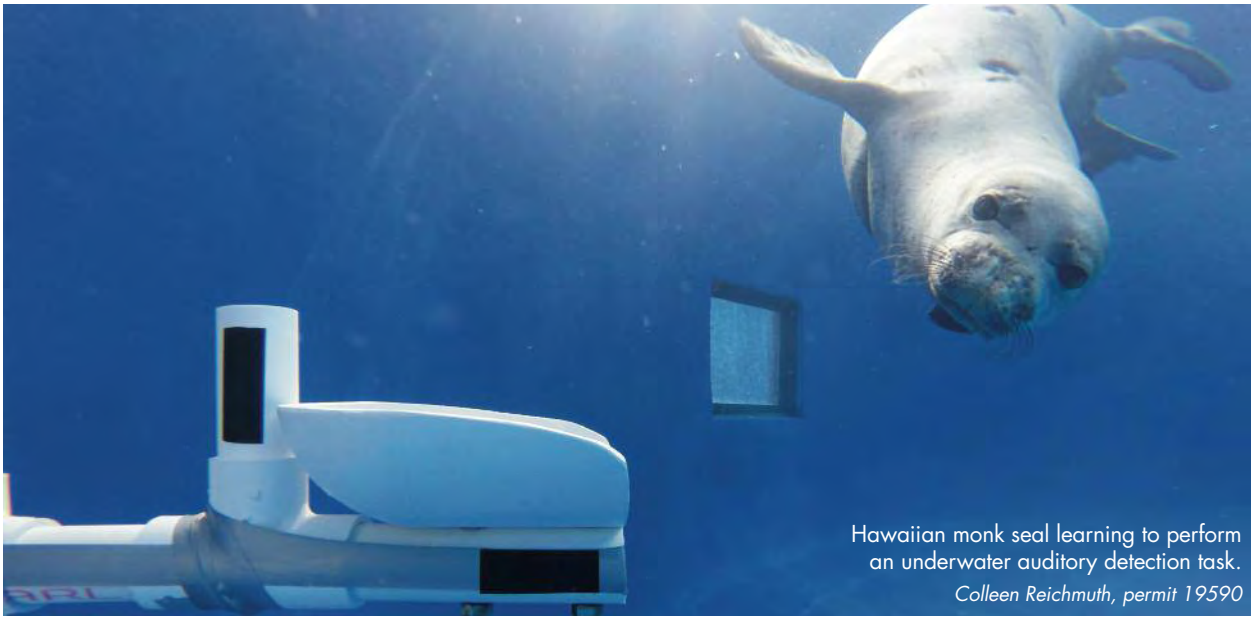
The Navy needs new data to improve the Navy's acoustic and explosive impact assessments for marine species. Priority interest is in species for which no, or insufficient, data are available. Areas of focus include audiograms of hearing capability in marine species, data on temporary threshold shift (TTS)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

PROJECT

Navy training and testing activities occur in waters surrounding the Hawaiian Islands, including areas overlapping habitat for the ESA-listed Hawaiian monk seal (*Neomonachus schauinslandi*). However, there is little bioacoustic data available for the monk seal, including information about hearing abilities and the 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 has succeeded in 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 have been 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. This project has also included evaluation of audio and video recordings of the seal's underwater sound production to provide previously unavailable descriptions of underwater calls emitted by male monk seals.

Researchers have just completed work with an adult male Hawaiian monk seal in residence at the University of California Santa Cruz's Long Marine Lab-



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


Hawaiian monk seal.

oratory. The seal was previously trained for cooperative physiological research and subsequently participated in hearing tests in the laboratory.

Experimental conditions were carefully controlled to minimize potential effects of unintended environmental sounds or behavioral cueing. The testing methodology involved 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 underwater sound production for the species. The underwater hearing test results revealed that Hawaiian monk seals hear better at lower frequencies than previously believed, although with poorer sensitivity than that of related species. 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 were 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. As for the underwater audiogram, this work initially entailed characterizing ambient noise, mapping the sound field and calibrating acoustic stimuli. Auditory thresholds measured 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 sub-family), in contrast to 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 confirmed that all analyzed calls were produced in water. 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. Results with one focal individual were validated by supplemental recordings of another captive male and by identifying unpublished observational data from free-ranging Hawaiian monk seals.

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

Work during 2020 focused on measuring masked hearing thresholds in-air and completing analysis of the underwater call repertoire. The project team's first manuscript was accepted for publication in 2020 and will appear in the journal *Endangered Species Research* in early 2021. They also drafted their second planned manuscript on terrestrial hearing in Hawaiian monk seals, which is expected to be available in 2021. COVID-19 travel restrictions delayed monk seal KE18's return to Hawaii, which had been planned for late 2020. The COVID-19 shutdown of the Long Marine Lab, accompanied by wildfires that forced evacuation of animals from the lab, slowed analysis and writing efforts, but the team worked hard to minimize disruptions. The planned research is expected to be completed in 2021. Given the importance of these data, the team is working towards replicating the auditory study with a second trained seal.

The results of this study 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.

Jillian Sills 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. Dr. Sills earned her Ph.D. in marine biology and biological oceanography at the University of California at Santa Cruz.

Key collaborators: Graduate students Kirby Parnell, University of California, Santa Cruz and University of Hawai'i; Brandi Rusher-Hill, University of California, Santa Cruz; monk seal specialists Traci Kendall and Beau Richter, University of California, Santa Cruz. The National Marine Fisheries Serive and Sea Life Park Hawaii helped to facilitate this research program.

Collection of Auditory Evoked Potential Hearing Thresholds in Minke Whales

Principal Investigator: Dorian Houser
Project Status: Ongoing, 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 Partnerships section, page 101, 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.

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.

Minke whale.
Wayne Hoggard, NOAA/NMFS

By the close of 2019, all necessary permits were in place and the project was approved by the National Marine Mammal Foundation (NMMF) Institutional Animal Care and Use Committee. 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 results will be invaluable to regulators, scientists, the U.S. Navy and others concerned with the potential impact of sound on mysticetes.

The first field season, originally scheduled for 2020, was canceled due to COVID-19 pandemic restrictions. Work in 2021, planned for the summer field season, will depend on the status of the pandemic in both the United States and in Norway as well as travel guidelines.

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.

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), Lars Kleivane, MSc (LKARTS Norway), James Finneran, Ph.D. (U.S. Navy Marine Mammal Program) 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: Ongoing, 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 Partnerships section, page 101, 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.

The project team plans to conduct a series of field experiments in a unique site near Queensland, Australia. The team will deploy a sound source from a vessel and will play upsweep tones at various frequencies (one frequency per treatment) to approaching whales. The source level of the tone will remain constant throughout experiment. The playback will begin when the whales are too far from the source to hear it (based on assumptions about their hearing in noise conditions). As the whales approach the sound source, the tones will become louder until, at some point, they become audible to the whales. At this point, the whales will change behavior, likely by avoiding the source vessel, as found in a previous experiment using a 2 kHz tone stimulus. 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


Humpback whales.

are transmitted, to provide a control sample. This will help quantify the behavioral response, as well as make sure the response is to the tone stimulus and not the presence of the vessel.

A four-phase experimental routine will be followed:

1. Tagging phase—Attempt to tag an adult whale in the experimental 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 additional *in situ* acoustic measurements and recover tag.

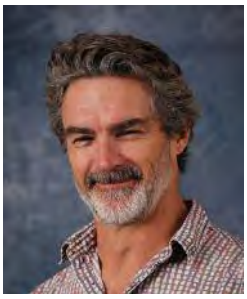
The study site provides several benefits, including much lower noise levels than many ocean sites. The site's acoustic environment has been extensively measured and characterized. Eleven previous field seasons at this site provide a wealth of background data on whale movements, normal behaviors and abundance,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

The original project schedule included a full field season in 2020. However, the field effort required skilled observers who would need to travel to, and be lodged in, the area. When the COVID-19 pandemic restrictions prevented travel into Australia and Queensland, as well as severely limiting lodging options, the core project team needed to revise their 2020 plan. Rather than lose an entire year, the two principal investigators conducted a pilot effort without assistants. Working at the planned site, they tested equipment and evaluated signal transmission and measurement under real field conditions. The results of the successful test runs will help to increase efficiency of the full field efforts, currently planned for September and October 2021.

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 already 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. Hearing data can also be incorporated into models used to assess the effects of various sound sources on mysticete behavior and physiology.

About the Principal Investigators

Rebecca Dunlop is a professor in physiology and animal behavior at the School of Biological Sciences, 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 a 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: Ongoing, 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. Often, AEPs measure the auditory brainstem response (ABR). 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 ABR 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 ABR 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 ABR amplitudes compared to tone burst stimuli and if narrowband chirps provide advantages (compared to tone bursts) for marine mammal auditory threshold testing.

Bottlenose dolphin.
Todd Pusser, NOAA

3. Determine if optimal chirp properties can be predicted from cochlear traveling wave speed (TWS) estimates and/or anatomical measurements of the cochlea.

Data are being collected with bottlenose dolphins (*Tursiops truncatus*) and will be collected with 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 in a more accessible species for testing.

During 2020 the project team was able to measure ABRs to broadband (1–152 kHz) noise bursts and high-pass noise (HPN) in several dolphins. The data were used to estimate cochlear TWS and to examine the relationship between noise burst duration and ABR amplitude. The team analyzed data examining relationships between stimulus offset and "offset ABR" in dolphins. Three manuscripts were completed and submitted to *The Journal of the Acoustical Society of America* on these topics. Two were published (see sidebar for citations) and the third was in review at the close of 2020.

Due to COVID-19 work restrictions, the team was unable to test California sea lions during 2020 as originally planned. Sea lion testing planned for 2021 (barring additional work and travel restrictions) is expected to include ABRs in broadband impulses and HPN. Based on those measurements, the team will derive cochlear TWS and optimal chirp properties. They will also measure ABRs to broadband and narrowband chirps.

The team plans to complete all measurements in dolphins in 2021, including ABRs to narrowband chirps and tone-bursts.

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

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.

2020 publications

Burkard, R., Finneran, J.J., Mulsow, J. and Jones, R. (2020). Offset auditory brainstem response (ABR) amplitude in bottlenose dolphins. *The Journal of the Acoustical Society of America*, 148(3):1445–1455. DOI: 10.1121/10.0001900.

Finneran, J.J., Mulsow, J., Strahan, M.G., Houser, D.S. and Burkard, R.F. (2020). Role of the temporal window in dolphin auditory brainstem response onset. *The Journal of the Acoustical Society of America*, 148(5):3360-3371. DOI: 10.1121/10.0002703.

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

Principal Investigators:
Aran Mooney, Wendy Piniak
Project Status: Ongoing, 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 TTS in these species. 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 auditory evoked potential (AEP) methodology will be used.

Red-eared slider.
Andria Salas

Eastern painted turtle.
Andria Salas

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 AEP measurements 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.

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 (SPLs) will start at lower levels and increase or decrease as needed to induce TTS (up to certain SPLs), after which durations will be increased or decreased to achieve targeted overall sound exposure levels (SELs).

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.

Although work in 2020 was delayed due to permit delays resulting from COVID-19 restrictions, the team did secure permits and acquire both turtle species. Initial work focused on refining testing methods, identifying variables to be addressed in testing and evaluating baseline threshold for the red-eared sliders. These tests were followed by AEP recordings and initial TTS onset evaluation.

Efforts in 2021 will focus on completing AEP and TTS evaluations in red-eared sliders and collecting comparative data with eastern painted turtles. Data analyses will follow testing in each species. Methods for evaluating auditory anatomical effects, such as hair-cell changes, will be completed and changes quantified following noise exposure.

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. 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 biologist at NOAA's NMFS. 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.

New Start Project

Frequency-dependent Underwater TTS in California Sea Lions

Principal Investigator: Ron Kastelein
Project Status: New Start, Project 45

NEED

N-0224-20: Frequency-dependent, Underwater, Temporary Threshold Shift in California Sea Lions

California sea lions commonly occur all along the western coast of the continental United States of America, including in Navy training and testing areas. Because there has been limited research on the susceptibility of California sea lion hearing to underwater sound, by measuring temporary threshold shift (TTS), the Navy needs additional data to determine appropriate criteria for impact modeling. Data that characterize frequency-dependent underwater TTS across the frequency hearing range of California sea lions are particularly needed.

PROJECT

This project is testing how sounds of different frequencies may affect the underwater hearing of California sea lions (*Zalophus californianus*).

The goals of the project are to

1. Establish underwater behavioral audiograms (hearing thresholds over the entire hearing frequency range of a species) for two more California sea lions. Currently behavioral audiograms exist for only four animals
2. Determine the TTS susceptibility of California sea lions over their entire hearing range
3. Determine TTS onset sound exposure levels (SEL), a unit that incorporates both the sound level and the exposure duration, and TTS growth after exposure to sounds of various frequencies and SELs
4. Based on the information derived in items 1-3, construct equal TTS curves (one of which is the TTS onset curve), which can be used to produce an auditory weighting function for California sea lions
5. Determine which hearing frequency is most affected by each fatiguing sound frequency
6. Determine the recovery rate of hearing after the fatiguing sounds stop
7. Test the equal-energy assumption, which will compare the TTS from two configurations: SEL composed of high sound pressure levels (SPL) for a short duration exposure versus the same SEL composed of a lower SPL for a longer duration exposure
8. Test the effect of duty cycle (percent of total time sound is being produced).

> The data will be directly applicable to all Navy environmental documents analyzing acoustic effects of tonal sounds.

Two California sea lions, an adult female and a young male, with excellent hearing are being tested within a pool complex designed for acoustic studies. The animals are exposed to the fatiguing sounds and their hearing is tested pre- and post-exposure. The fatiguing sounds are continuous 1/6th-octave noise bands. Fatiguing sounds with the center frequencies 0.5, 1, 2, 4, 8, 16, 32 and 40 kHz are being tested, with a one-hour exposure duration. This approach is similar to the methods this team used in previous LMR-funded studies of harbor seals (*Phoca vitulina*) and harbor porpoises (*Phocoena phocoena*), so results can be compared directly among the three species.

The two California sea lions involved in the TTS.
Ron Kastelein, SEAMARCO

The equal-energy assumption study is collecting data to address potential effects of naval sonar that often operates for shorter durations and at higher sound levels. This study is evaluating two frequencies (4 kHz and 8 kHz) with five exposure durations (10, 20, 40, 64 and 80 minutes) with five different SPLs: all duration and SPL combinations leading to the same SEL.

Six duty cycles have been tested: 2.5 (representative duty cycle of 53C sonar), 60, 70, 80, 90 and 100 percent. Assessing duty cycle effect for the 4 and 8 kHz exposures will provide data on both the closest frequency to the actual signal of interest (4 kHz) and the scalability of the TTS as a function of duty cycle at 8 kHz.

Data collection at three frequencies—2, 4 and 8 kHz—is complete and 16 kHz testing was initiated at the end of 2020. Data for the equal energy assumption study and the duty cycle study was also collected during the 4 and 8 kHz tests. A manuscript presenting results from the 2 and 4 kHz tests will be submitted for peer review in 2021.

Work planned for 2021 includes completing testing for 16 kHz and beginning work on 1 and 32 kHz. A manuscript for results of 8 and 16 kHz is also planned during 2021.

Manuscripts on other frequencies will be prepared and submitted throughout the project, following sets of testing. The overall project completion is expected during 2023.

Navy acoustic impact criteria use auditory weighting functions to predict the onset of TTS and PTS as functions of sound frequency. This project will produce data (a 6 dB TTS onset curve) that can be used to improve the weighting function of otariids (eared seals) for environmental impact assessments. The data will be directly applicable to all Navy environmental documents analyzing acoustic effects of tonal sounds (e.g., sonars).

About the Principal Investigator

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

INVESTMENT AREA 2
DATA PROCESSING AND ANALYSIS TOOLS

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

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

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

The following section includes summaries of five ongoing projects. The planned start to one of these projects, Project 44—Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales, was delayed due to COVID-19 restrictions.

The ongoing projects are

1. Project 31—DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling
2. Project 36—Analytical Methods to Support Development of Noise Exposure Criteria for Behavioral Response
3. Project 42—ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation
4. Project 43—MSM4PCoD: Marine Species Monitoring for the Population Consequences of Disturbance
5. Project 44—Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales.

Lance Cpl. Mackenzie Binion

Ongoing Projects

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

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

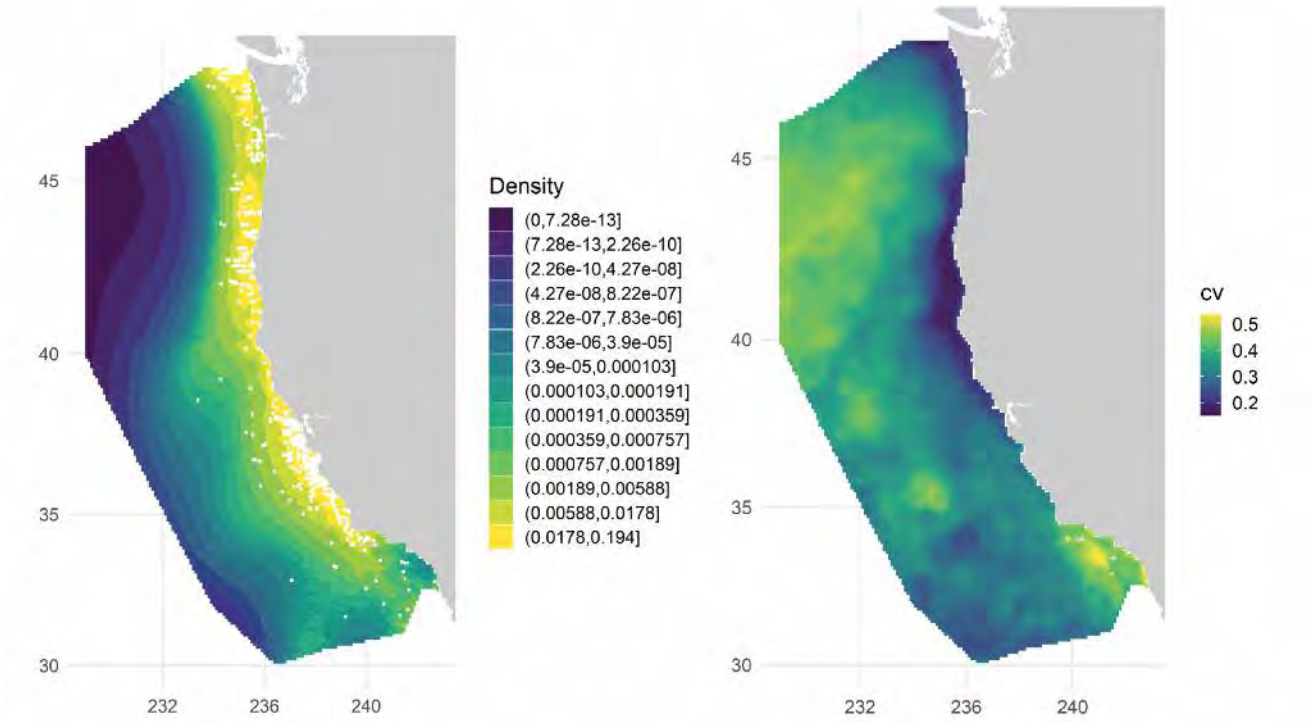
NEED

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 can be applied to data collected from surveys of biological populations. One method, called a density surface model (sometimes called a spatial or habitat 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.



Predicted mean density (animals km^{-2}) and associated coefficients of variation (CV) from the 1991–2018 habitat-based density models for humpback whales. Panels show the multi-year average density based on predicted daily cetacean species densities covering the 1996–2018 survey periods (summer/fall). Predictions are shown for the study area (1,141,800 km^2). White dots in the average plots show actual sighting locations from the SWFSC 1996–2018 summer/fall ship surveys for the respective species.

Jason Roberts, Duke University

Right whale.
NOAA/NMFS

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—the University of St Andrews, Duke University and four regional NOAA Fisheries labs (Northeast, Southeast, Southwest and Alaska Fisheries Science Centers)—lead the development and application of the survey and analysis methods used 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 project team is developing concrete guidance on best practices in this type of modeling.

The 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 workshop attendees.

Reports from these public workshops can be found at the DenMod website (synergy.st-andrews.ac.uk/denmod). The fourth meeting was held virtually in November 2020 (details below).

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

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 subgroup 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 subgroup has been testing and implementing the variance propagation method within Southwest Fisheries Science Center density surface models. A manuscript describing the variance propagation tool for estimating variance in density surface models has been accepted for peer-reviewed publication.

During 2020, the group continued to investigate sources of uncertainty and developed a simula-

tion-based approach that includes multiple sources of uncertainty. The model simulates possible model predictions under different conditions. An example application can be found in NOAA *Technical Memo NMFS-SWFSC-638* (see sidebar for citation).

Extrapolation

The Navy requires density estimates in areas beyond the bounds of the survey data. Such extrapolation makes assumptions on the correctness of the model used. During 2019 this subgroup drafted a guidance document along with a software toolkit (dsmextra), available at density-modelling.github.io/dsmextra.

The subgroup in 2020 continued to work on extrapolation issues and developed methods for addressing this when setting up a model. The peer-reviewed manuscript, dsmextra: Extrapolation Assessment Tools for Density Surface Models, was published in 2020 in *Methods in Ecology and Evolution* (see sidebar for citation).

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

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 subgroup has been looking at the similarities between existing methods to ensure that practitioners are using the best possible methods and not investing time and resources in new methods that provide little benefit. They have completed a mathematical comparison of different spatial modeling approaches. Two peer-reviewed articles have been published—one in 2019 and a second in 2020 in the *Journal of Agricultural, Biological, and Environmental Statistics* (see sidebar citation). Two more are being prepared. This topic will be revisited later in the project.

Workflow

Many data preparation and modeling workflows have evolved over time within the different organizations that provide density estimates to the Navy. The workflow subgroup led an effort to encapsulate this information. During 2019, the subgroup 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.

Pinnipeds (seals and sea lions)

This subgroup 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 subgroup is focused on working out how best to use and combine these disparate data. A manuscript describing the advancements that have been made is being drafted, led by the team at the Alaska Fisheries Science Center.

Acoustic and visual data integration

This subgroup 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.

In 2020 the group determined that the best possibility for conducting a comparative study would involve modeling deep diving odontocete (toothed whale) species using data from selected shipboard surveys. This may require additional analysis of the acoustic data for the selected species.

Data integration

This subgroup, 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 (2021) of the project.

Additional effort during 2020 also addressed requests from NOAA Fisheries Science Centers for software tools for modeling, validation and other analysis needs.

The project held its fourth workgroup meeting in November 2020. Due to COVID-19 travel restrictions, it was a virtual meeting. Participants agreed on priority topics for 2021, which will include addressing animal group size, data integration and incorporating data from underwater autonomous vehicles (UAVs). Work on other topics will also be completed.

Meetings scheduled for 2021 include a UAV workshop (to be held online) and the final working group meeting and public workshop, which are currently planned to be held alongside 2021 Society for Marine Mammalogy Biennial conference in December 2021.

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 L. Miller and Catriona M. Harris, University of St Andrews; Pat Halpin, Jason Roberts and Rob Schick, Duke University.

2020 Publications

Becker, E.A., Forney, K.A., Miller, D.L., Fiedler, P.C., Barlow, J. and Moore, J.E. (2020). Habitat-based density estimates for cetaceans in the California Current Ecosystem based on 1991–2018 survey data. *NOAA Technical Memo NMFS-SWFSC-638*.

Bouchet, P.J., Miller, D.L., Roberts, J.J., Mannocci, L., Harris, C.M. and Thomas, L. (2020). dsmextra: Extrapolation assessment tools for density surface models. *Methods in Ecology and Evolution*, 11(11):1464–1469. DOI: 10.1111/2041-210X.13469.

Miller, D.L., Glennie, R. and Seaton, A.E. (2020). 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.

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

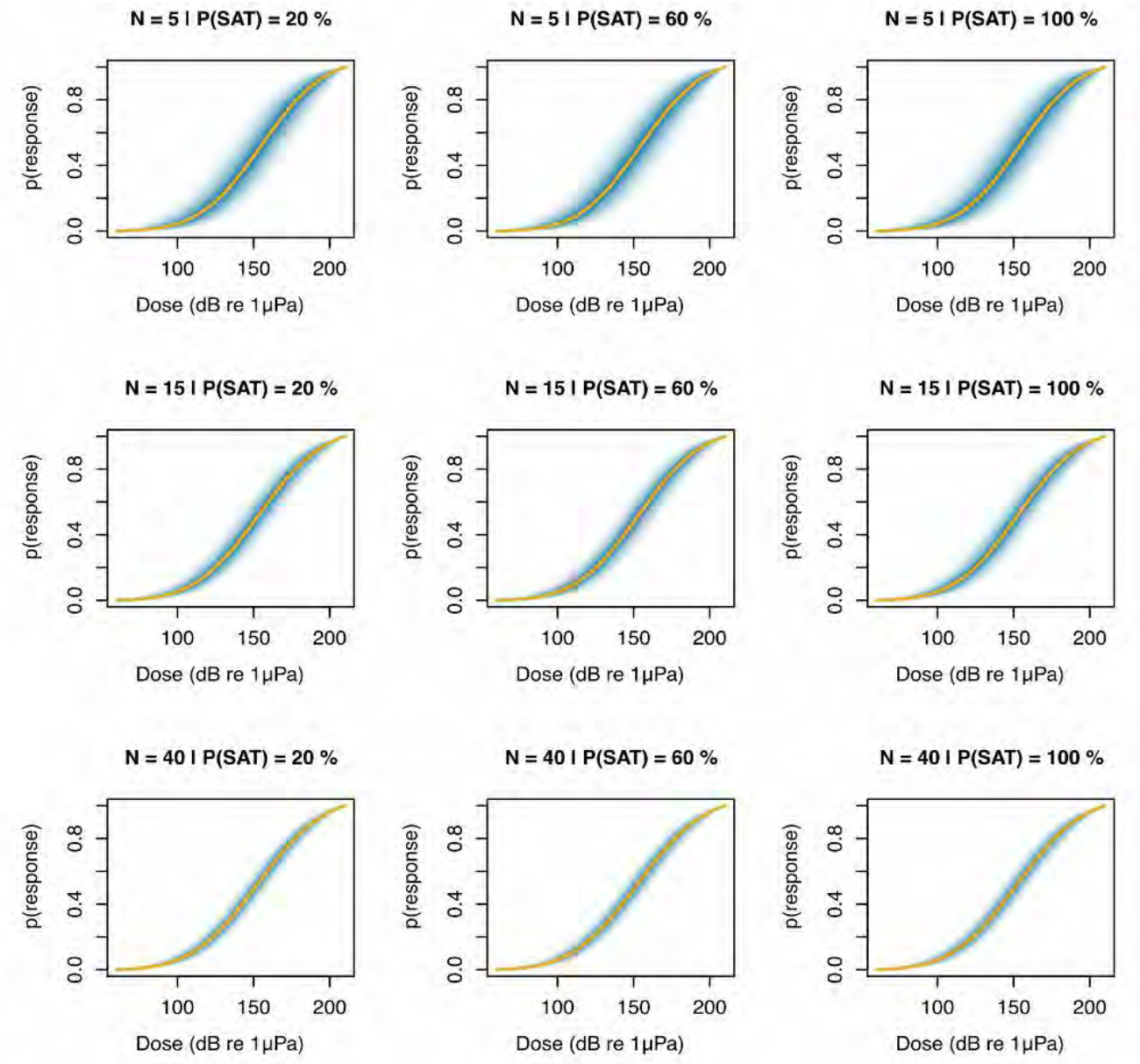
The project team is building on outcomes of the ONR MMB-funded MOCHA (Multi-study Ocean Acoustics Human Effects Analysis) project (synergy.standrews.ac.uk/mocha) to develop a new model selection method. They are investigating alternative dose-response functional forms (e.g., biphasic functions), and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

Species groupings will be one output from the analysis of the full data set and, from this, the team will derive dose-response functions for each selected species group. They are also evaluating

explicitly how contextual variables contribute to outcomes. A priority variable 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 and formats. The team collated the data from controlled exposure experiments (CEEs) for a wide range of variables including exposure history, signal type, animal behavior (foraging/non-foraging) in pre-exposure period, distance between source and animal and 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.

Using CEE data that included high-resolution data from digital acoustic tags (DTAGs) and low-



Example dose-response curves estimated for a range of sample sizes (N) and proportions of animals fitted with satellite tags (P(SAT)). The solid line represents the average posterior median across Ns=500 simulations, followed by the average 5%, 10%, 15%....and 95% credible intervals in darker to lighter shades of blue.

resolution data from satellite tags, the project team conducted a simulation study to investigate the balance between the data types and the effect of uncertainty in received levels from both data types on the resulting dose-response functions (see figure showing curves). The team presented the results to the environmental compliance team. The results are available through a technical report available at http://hdl.handle.net/10023/19909 and have also been submitted for peer-reviewed publication.

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

In 2020, the project team focused on testing and completing the model selection methods and applying methods to the full data set. Bayesian hierarchical dose-response models with a reversible-jump Markov chain Monte Carlo (RJMCMC) model selection algorithm have been implemented in the R programming language. The R functions have been generalized to apply to any number of species, and to allow the selection of both contextual covariates (both continuous and categorical) and functional forms for the dose-response relationship (mono vs. biphasic). In addition, the code has been adapted to allow species groupings and functional forms to be specified *a priori*, in recognition that parameter estimation for pre-determined species groupings (e.g., based on hearing sensitivity) may be of interest to the Navy. The code has been tested on simulated data and has been benchmarked against other model selection methods. Testing on subsets of real CEE data is underway.

The team expects to complete all data analyses in 2021 and to share results with stakeholders, including the Navy and National Marine Fisheries Service. A manuscript detailing the work will be submitted for peer-review and publication.

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 is a senior research fellow at, and Deputy Director of, the University of St Andrews Centre for Research into Ecological and Environmental Modelling (CREEM). Her research focuses on the impact of anthropogenic noise on marine mammals, specifically behavioral responses of marine mammals to noise, for over seven years. Dr. Harris holds a Ph.D. from the University of St Andrews.

ACCURATE: ACoustic CUe RATEs for Passive Acoustics Density Estimation

Principal Investigator: Tiago Marques
Project Status: Ongoing, 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. Cue rate is a fun-

Blainville's beaked whale.
Marie C. Hill, NOAA

damental multiplier required to convert the number of detected sounds into an estimate of animal abundance or density. 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 tasks include

- Identifying, reviewing, compiling and providing open access to all data available on cue rates (and their variability) across deep diving and baleen whale species
- Developing methods to estimate cue rates from different data types (e.g., time-depth data) and for different taxa
- Applying these methods to species of interest for the Navy
- Exploring the factors that determine cue rate variability over time and space
- Evaluating impacts of cue rate variability on density estimates from cue-based methods.

During its start-up in 2020, the project initiated several tasks. First was 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. Project participants established online options for other researchers to provide references and recommendations for PAM data sources. These include a dedicated email (papers4accuratereview@gmail.com) and an information and contact page at Research Gate (www.researchgate.net/project/ACCURATE-ACoustic-CUe-RATEs-for-passive-acoustics-density-estimation), also supported by requests sent to MARMAM email list. The ACCURATE team hopes to be able to collaborate with any other teams that might have relevant data and information on the topic, with a natural focus on, but not exclusive to, other LMR-funded projects.

Team members also began working with researchers who deploy animal tags on marine mammals to secure digital acoustic tag (DTAG) data and extract whale vocalizations (e.g., click data). Thus far this ongoing task has secured data from over 700 tag (mostly DTAGs) deployments. Tagged species include Blainville's beaked whales (*Mesoplodon cavirostris*), Cuvier's beaked whales (*Ziphius cavirostris*), pilot whales (*Globicephala melas*) and sperm whales (*Physeter macrocephalus*). Cues and cue types from each processed tag are being counted to obtain a cue rate per tag. The estimated cue rate per tag then will be combined into a simple cue rate per species. Where possible, factors affecting cue rate will be identified.

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

Additional tasks started in 2020 include

- Evaluating methods for cue rate estimation in baleen whales. Sensors on high sampling rate tags from fin whales and right whales are the initial focus of the project
- Estimating cue rate from proxy data, such as data from non-acoustic tags that still provide certain behavioral insights
- Investigating inter-click interval (ICI) patterns for deep divers (e.g., Cuvier's and Blainville's beaked whales).

Pilot whale.
Adam Li, NOAA/NMFS

Work in 2021 will focus on concluding the bibliographic review and tag data processing and analyses, while continuing cue rate estimations for baleen whales, estimations from proxy data and ICI pattern investigations. Two additional tasks expected to start are analyzing deep diver cue rate variability, with sperm whale data from towed arrays as a case study, and evaluating how signal detector/classifiers might affect cue rate estimation.

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 A. 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: Ongoing, Project 43

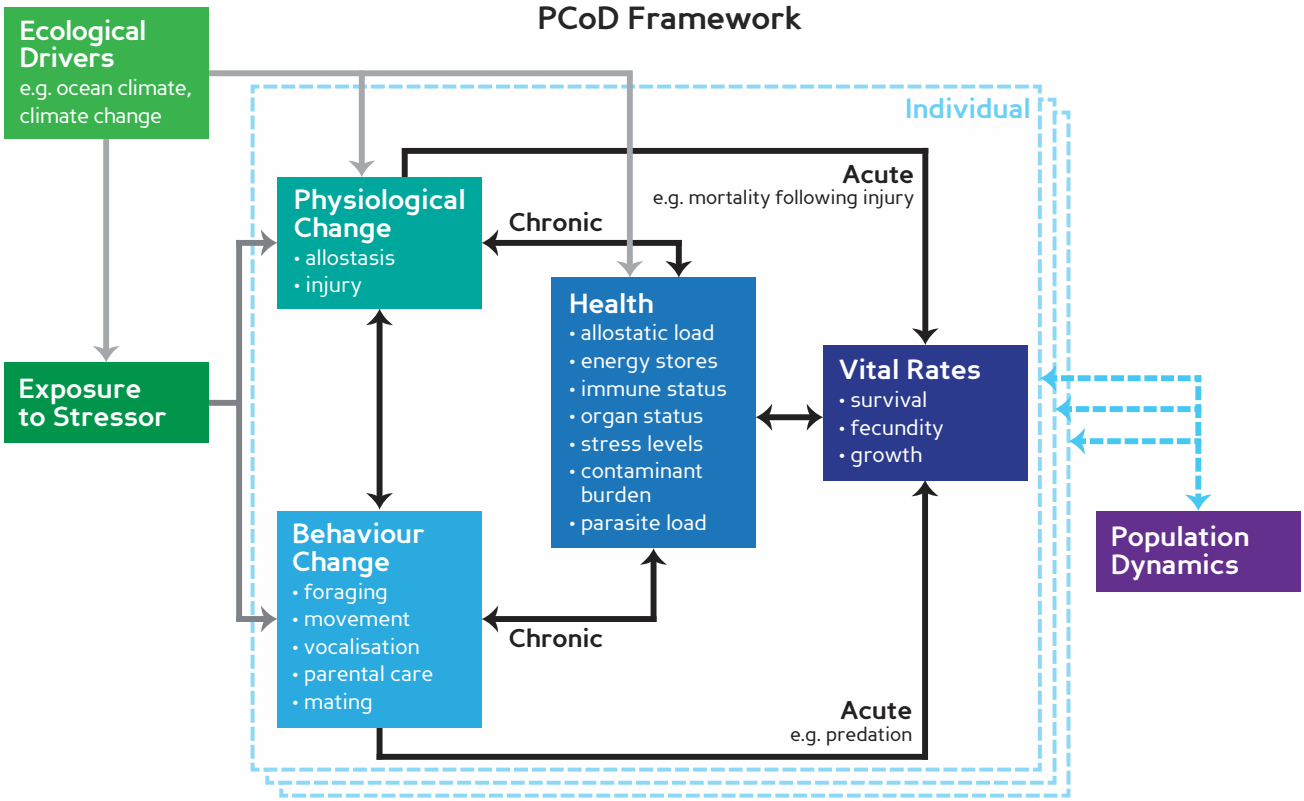
NEED

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 three core steps in the project's plan are:

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 20 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.
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.

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

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

In 2020, the project team began by holding meetings with Navy stakeholders to review monitoring objectives and efforts to date and to discuss and potentially refine the scope of the project. During review meetings and a scoping workshop, participants worked to focus the scope of the project and agree on next steps to ensure the project would support Navy needs. Parameters discussed included geographic regions for Navy monitoring and species within regions that were priorities.

False killer whale.
Wayne Hoggard, NOAA/NMFS

The priority regions (in alphabetical order) and species defined for the project were

- Atlantic Fleet Testing and Training (AFTT)
  1. Cuvier's beaked whale
  2. Short-finned pilot whale
  3. Sperm whale
  4. Humpback whale
  5. Fin whale
  6. North Atlantic right whale
- Pacific (Hawaii & SOCAL-HSTT)
  1. Cuvier's beaked whale
  2. Blainville's beaked whale
  3. Short-finned pilot whale
  4. False killer whale
  5. Humpback whale
  6. Minke whale (lower priority)
  7. Bryde's whale (lower priority).

Efforts in 2021 will begin to undertake the principal tasks of reviewing applicable current and historical MSM projects and methodologies for the identified priority regions and species, selecting metrics and conducting power analyses on the proposed metrics.

Overall project 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.

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, Megan Ryder, Ursula Verfuss and Rachael Sinclair, SMRU Consulting, University of St Andrews, UK; Len Thomas and Eiren Jacobson, CREEM, University of St Andrews, UK.

Demonstration and Validation of Passive Acoustic Density Estimation for Right Whales

Principal Investigators:
Susan Parks, Len Thomas
Project Status: Ongoing, 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 modeling. 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

Southern right whales.

North Atlantic right whale.
NOAA

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 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 3km 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.

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

Finally, the visually obtained density estimation 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.

Field efforts planned for 2020 were delayed due to COVID-19 pandemic restrictions. This also prevented the planned acoustic density estimations, which were to be based upon the data from the field efforts. Work in 2021 will depend on the status of the pandemic in both the United States and in Brazil as well as associated travel guidelines.

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.

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 section includes summaries of three ongoing projects. Each project experienced some level of delay due to COVID-19 restrictions.

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

MC3 William Hardy

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.

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

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


Right whale.

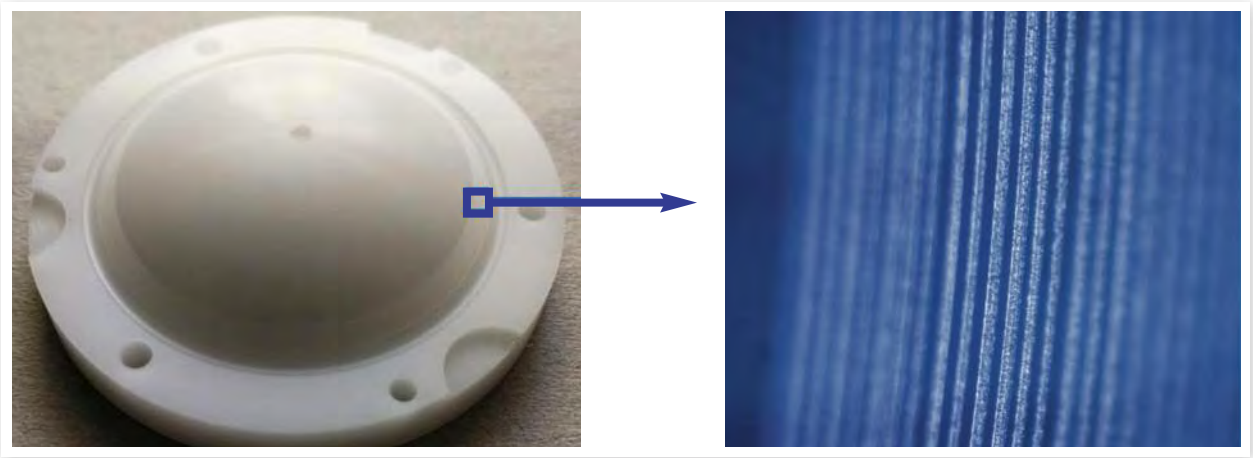
of Jacksonville, Florida. This training range is one of the identified priority regions for the LMR program and the Navy.

Poor tagging conditions during the 2017 monitoring season prevented testing the new tag attachments on right whales. The team 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 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.

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

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



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

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, analyses suggest that each cup version appears to offer benefits related to an animal's speed and skin condition.

In addition to suction cup materials and textures, the project is evaluating if biocompatible glues can safely offer additional attachment durations. Glue work in 2020 converged on a cyanoacrylate adhesive, then moved to design and testing the cup material/adhesive combinations under laboratory conditions. Testing focused on attachment, strength and release mechanisms.

COVID-19 pandemic restrictions prevented the planned 2020 field testing of the final cup/adhesive design. Work in 2021 will depend on the status of the pandemic and associated travel opportunities.

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.

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, a biologging tag, is often used for research and monitoring when both acoustics and movement of the animal are of interest. DTAGs are highly integrated, compact, low-power, high-fidelity acoustic biologging 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 has been focused on building a pool of new (third) generation DTAGs (DTAG-3s) to enhance availability of the instrument for behavioral response research. A key innovation, the tag lease program, makes the tags readily available and sustains continuing improvements in tag design.

Building on the DTAG designs that were created with support from the ONR MMB program, the project has streamlined tag manufacturing to produce field-ready tags. The tags are leased to researchers on a monthly basis, with support and technical advice for the field effort provided as needed. When fieldwork is completed, tags are returned for inspection and testing. The researchers who used the tags under rigorous field conditions provide feedback, which is used to inform design improvements for field reliability and performance. Importantly, the revenue generated by the leasing pool is applied to the costs of improving tag designs and manufacturing new field-ready tags.

The project successfully produced and fielded the 20 pool tags from the original proposal and has used the funds generated by the leasing program to produce additional tags. 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 had been increasing 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 usage amount from 2016. The 2020 field season was an exception, as noted below, due to COVID restrictions.

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

The latest DTAG design, the DTAG-3+.
Alex Shorter

An attached DTAG-3+.
Marc Lammers, permit 19655

during 2018, as was the integrated VHF transmitter. During 2019, tag antenna configurations were tested to evaluate tradeoffs in increasing VHF tracking distances with changes to the tag design. The most recent version of the tag now includes an improved antenna based on results from these experiments.

Design improvements in 2020 included adding sensors to the tag assembly while reducing mass and volume by 30 percent. Two units of this new version, the DTAG-3+, were produced. The new units include Fastloc® GPS and Argos capabilities, and an improved VHF antenna design. Although with fewer field efforts supported due to COVID-19 restrictions, the new designs were tested at two field sites in Fall 2020. The field effort reductions also cut the number of tag months in 2020 by roughly half the number in 2019.

Additional work in 2020 focused on algorithm development to help users process the data coming from multiple sensors within the new DTAG-3+. Algorithm development is focused on improving data processing of the position (from both GPS and depth sensors), orientation (from both accelerometer and magnetometer) and speed (from both depth and acoustic sensors). This work will enhance the information that users extract from the data recorded by the DTAG-3+.

In 2021, the team plans to complete eight additional DTAG-3+ units (total of 10). In addition, the team hopes that field work will begin to pick back up, which will provide additional feedback on the new design. Work will also continue on the algorithm development to process the data coming from the DTAG-3+.

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.

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

Principal Investigator: Russ Andrews
Project Status: Ongoing, 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 redesign 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

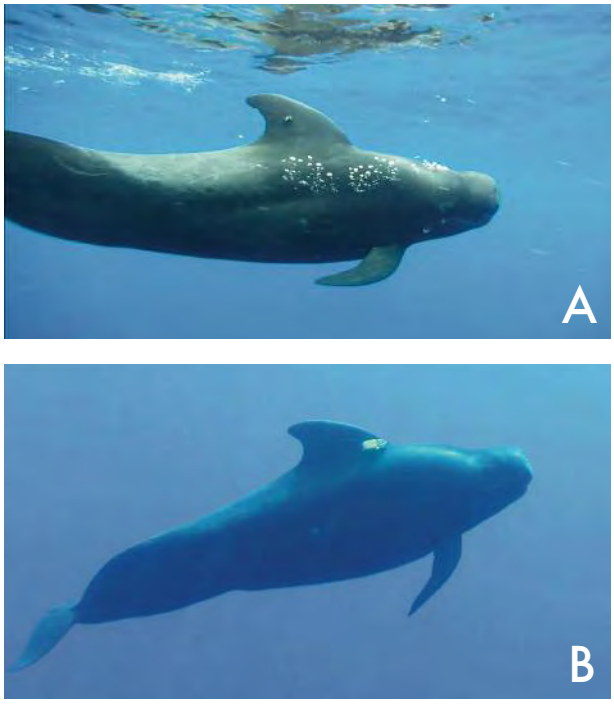
This demonstration project is building on previous Office of Naval Research-funded efforts to assess the feasibility of producing an alternative tag attachment element for remote tag deployment. The current attachment for the Low Impact Minimally Percutaneous External-electronics Transmitter (LIMPET) 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 and
- Designed to work with the current suite of LIMPET tags and Sound and Motion Recording and Transmitting (SMRT) tags.

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

Phase 1

Refine two existing designs: 1) an elastic connection between a more tissue-friendly implanted



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 permits 15330 and 20605

Short-finned pilot whales.
Adam U, NOAA/NMFS

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.

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). 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.

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.

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, his-

tological 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.

> Improved attachment mechanisms that support recording the movements and behavior of cetaceans over longer periods of time will improve the Navy's ability to monitor cetaceans.

Phase 1 of the project, originally slated for completion in 2020, saw some COVID-19-related changes and delays. When personnel and access to real whale tissue became limited, the work plan had to be modified. Computer modeling of tissue and prototype anchor interactions ceased and work focused more on physical prototype design and testing. This involved developing appropriate simulated tissue for more repeatable testing of attachment designs. Once a material was developed, various prototypes of the two attachment designs were tested, including comparing insertion force and retention strength. Additionally, because the new attachments may be heavier than existing darts, the project team reviewed available projectors for remote tag delivery to determine whether new off-the-shelf options can be used successfully with heavier, more robust tag attachments.

Based on the testing already completed, tag implant prototypes will be completed by the end of 2021 and final designs selected for field testing. Depending on the decisions for subsequent Phase 2 and the status of COVID restrictions, field deployments of initial designs are planned for 2022.

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.

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.

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.

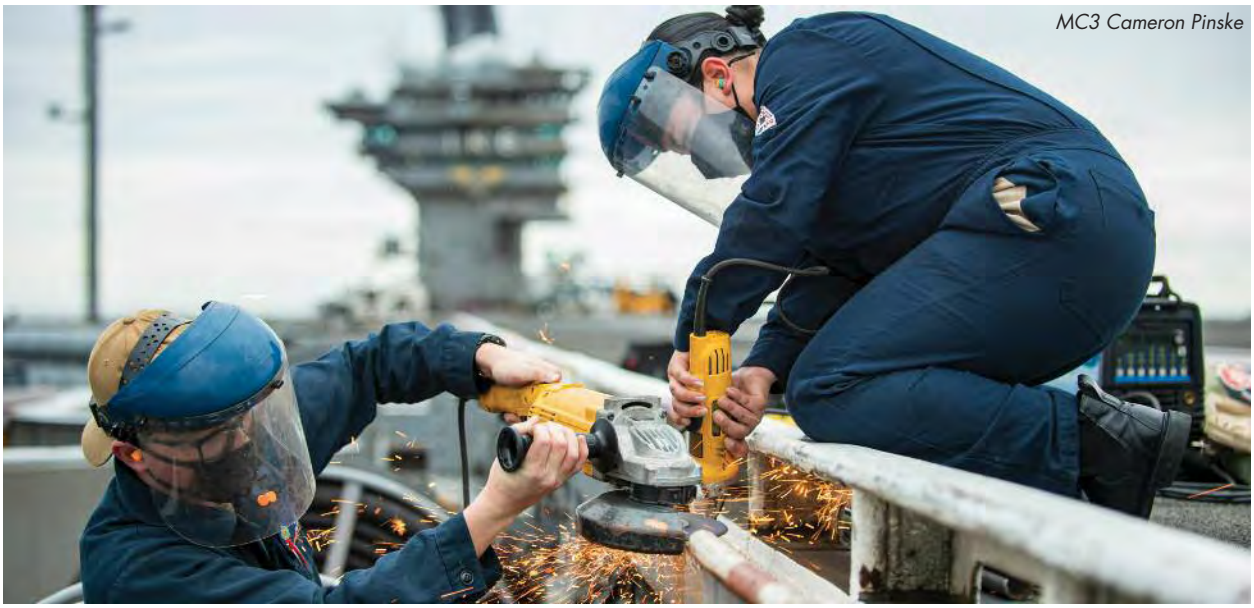
The following section includes summaries of one ongoing project and one new start project.

The ongoing project is

1. Project 34—Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar.

The new start project is

1. Project 46—Capability Enhancements for Tethys, a Passive Acoustic Metadata Workbench.



MC3 Cameron Pinske

Ongoing Project

Standardizing Methods and Nomenclature for Automated Detection of Navy Sonar

Principal Investigators: Elizabeth Henderson, Susan Jarvis, Tyler Helble
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.

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.

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

Guided-missile destroyer USS *Gravely* (DDG 107).
MC2 Sean Rinner

An MH-60R Sea Hawk helicopter departs the flight deck of the guided-missile destroyer USS *Dewey* (DDG 105).
MC2 Devin M. Langer

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.

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.

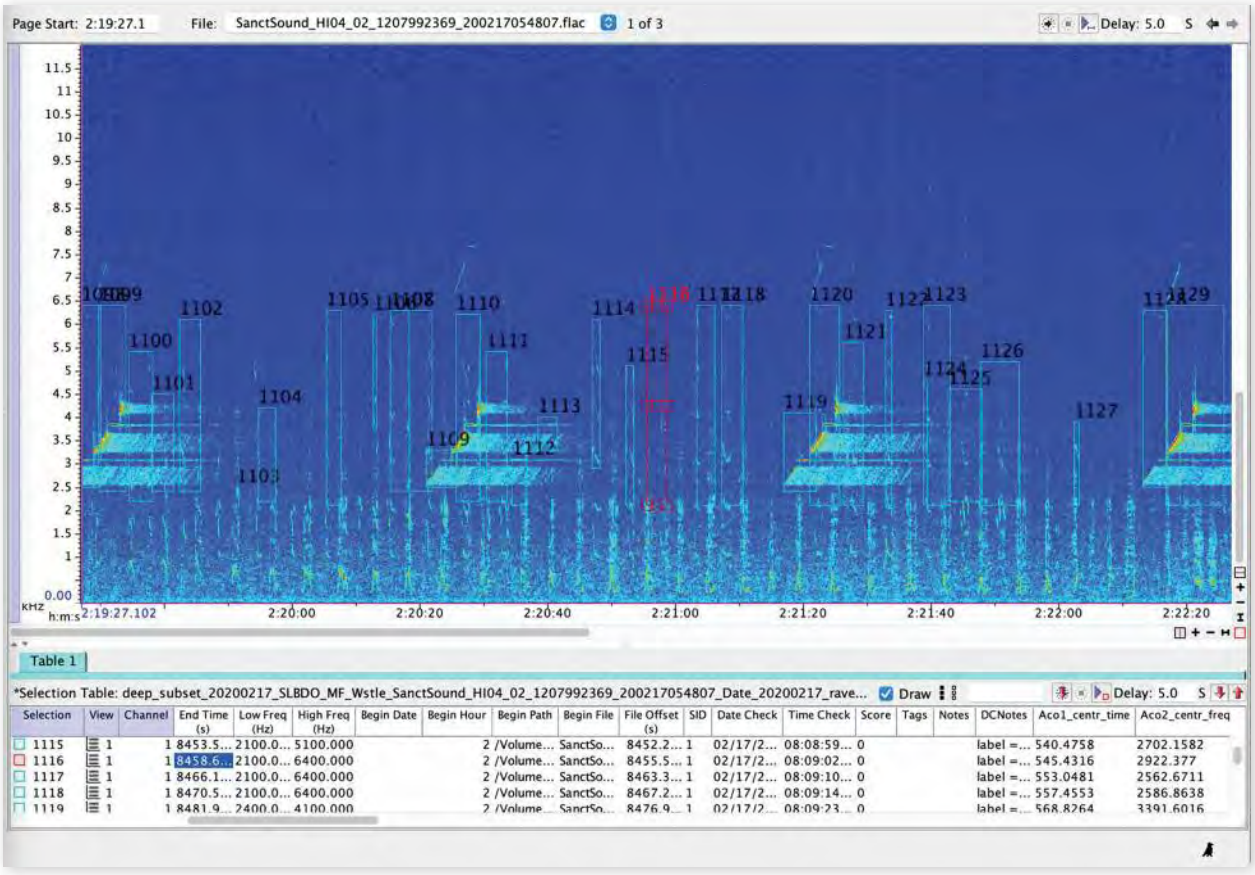
The literature review examined papers and reports with descriptions of sonar, including AN/SQS-53 hull-mounted, DICASS sonobuoys and AN/AQS-22 dipping sonar. The effort highlighted characteristics such as frequencies, source levels, sonar components, duty cycle, bandwidth and others. It also included 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.

Other work during 2019 included running 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 helped 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.

Work in 2020 focused on more in-depth analyses of detector capability comparisons and applying detectors to more data sets. The team focused on using Raven-X as the analysis platform and worked to incorporate the existing detectors mentioned above. Using the Raven-X platform, the team is able to run all the detectors in parallel on the same data set, over a variety of detector settings. This capability is instrumental for properly comparing the detectors in a timely manner. Raven-X was also used to train a machine learning "net" for the GPL and Cornell detectors. Initial results indicate that no single existing detector will be adequate for new deployments. They might, however, provide a good starting point for an updated approach.



Validating sonar detections from Raven-X using the Raven review tool.
Mid-frequency active (MFA) sonar can be seen in the presence of humpback whale calls.

COVID-19 restrictions during 2020 did slow some planned work to compile a standardized passive acoustic data set from Navy range data, although the Navy members of the team continued to the extent possible. The data sets include multiple examples of Navy sonar, such as hull-mounted sonar (e.g., AN/AQS-53C) operating in varying 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 helps to establish a benchmark of the necessary characteristics of broadly applicable sonar detectors. Unclassified data recorded on non-Navy recorders was also included in the analysis. These data included additional types of sonar signals recorded both in the Pacific Ocean and Atlantic Ocean from a variety of depths to provide environmental differences in the data as well.

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

Plans for 2021 include completing applying detectors to data sets, developing both a standardized detector and classifier as well as the standardized nomenclature, and preparing supporting recommendations and documentation. The project team plans to consult the appropriate sonar warrant officer to ensure that investigators know what the source properties of each sonar signal should be and that any nomenclature used is unclassified.

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.

Tyler Helble is a bioacoustics scientist and electrical engineer at the Naval Information Warfare Systems Center, Pacific. Dr. Helble earned his Ph.D. in Applied Ocean Sciences at the University of California San Diego. His main area of focus is developing tools for detection, classification, localization and density estimation of cetaceans using passive acoustics.

New Start Project

Tethys Capability Enhancements

Principal Investigator: Marie Roch
Project Status: New start, Project 46

NEED

N-0228-20: Marine Mammal Acoustic Software Application Enhancements

The Navy's need for efficient methods to analyze passive acoustic data continues to grow with the increasing amount of data collected by the Navy's Marine Species Monitoring Program. While publicly available acoustic analysis software applications have improved over the years, additional improvements are needed to enhance overall processing efficiency when identifying, characterizing and cataloging acoustic signals of interest.

PROJECT

This project is enhancing Tethys, a workbench and standardization scheme for archiving and using acoustic metadata. Tethys offers researchers and mitigation specialists a method to record these data in a manner that can be preserved over long time periods and accessed from a variety of platforms such as web browsers, MATLAB®, Java, Python and R.

The current version of Tethys was developed under a previous LMR project (Project 18, page 26), which was co-funded by the Bureau of Ocean Energy Management (BOEM). That project built upon early work funded by the Office of Naval Research Marine Mammal Biology program. As the Tethys user group expanded and became increasingly diverse, the need for additional enhancements to make the workbench more accessible became apparent.

This new project is working to address following five key enhancements.

1. **Technology updates to ensure security and prevent obsolescence**

   There are two primary components that are targeted for upgrade. The server code is being migrated to the most recent version of Python. This requires minor code changes to the core code base and reengineering functionality to account for library packages that are no longer supported. The second major direction of the code update is the replacement of the underlying data storage technology to upgrade the database engine to the most recent version of Oracle's Berkeley extended markup language database (Berkeley DBXML). Recent changes to the system provide high-performance indices which will provide additional scalability.

2. **A drag-and-drop data import interface**

   While the current data import methods are both usable and teachable, user feedback indicates that the text file specification requirement now in place can be confusing for new users. This project will build an alternative method that provides a drag-and-drop type interface. The goal is to combine a simpler interface with a software agent that offers advice, such as suggestions on potential matches for common non-standard data field names and help on fields that are required but not yet matched.

3. **An advanced mapping interface**

   The project will migrate from the current proprietary Google Maps application programming interface to the open-source OpenLayers map library. The team will provide the capability to add data layers on existing web client maps. The project team anticipates that this will provide improved functionality over what can be implemented with the current Google Maps interface. It will support overlaying oceanographic and atmospheric data (sea surface temperature, wind, etc.) onto animal detections,

and when applicable, the ability to show the evolution of these data over time.

4. **A beta-user program**

   The Tethys team will engage with a set of bioacoustics "power users" identified by the LMR program. The team will provide a set of educational resources, direct training and responses to issues identified by these users. Training could include a combination of short online sessions and one multiple day in-person training. Feedback from this set of users will influence whether and how to proceed with optional tasks.

5. **Responsive help and enhancements to address user needs**

   Experience has shown that each user group can have specific data organization needs that are not currently addressed within the Tethys schema. The project team will continue, within reasonable levels of effort, to provide necessary enhancements and training. The team also will remain alert to potential overlaps of needs among user groups to avoid duplication.

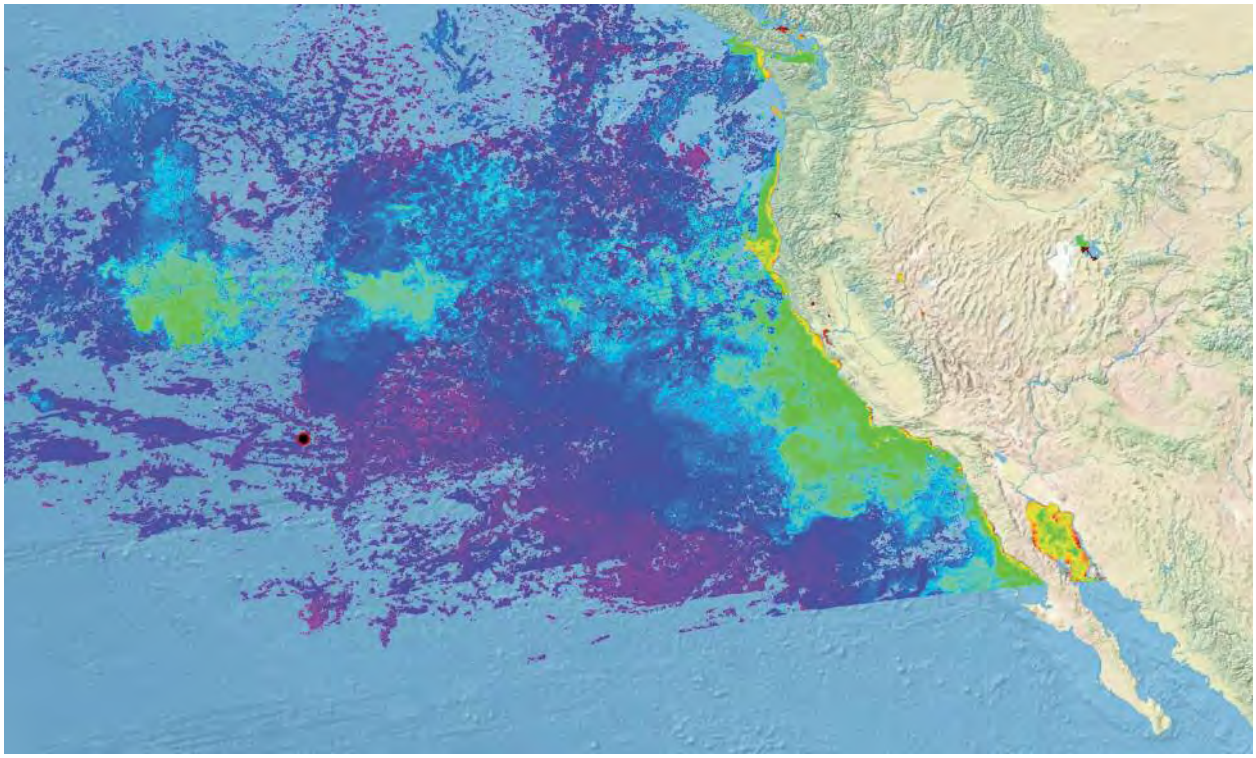
Three optional tasks have been identified that might be considered as the project proceeds. These are:

1. **PAMGuard/Tethys integration**

   The team would develop interfaces between Tethys and PAMGuard to enable a seamless transfer of PAMGuard detection and localization data to Tethys.

2. **Database consultant review**

   A database technology company, identified by the LMR program, would review the technologies used in the Tethys project, with the goal of identifying areas that could be improved and lead to desired outcomes such as a central repository. The Tethys team would provide time to support the review.



An open-source OpenLayers map showing chlorophyll concentrations in the Eastern Pacific. This is an example of environmental data the new mapping interface library would provide for overlaying with monitoring data, such as marine mammal tracks or detections.

Humpback whale.
Tom Kieckhefer, NOAA/NMFS

3. **Standards development**

   Previous Tethys work included moving the Tethys schemata towards an American National Standards Institute (ANSI) standard. The existing standards committee has addressed many of the issues related to deployments, detection and classification. However, the beta user group noted above may identify additional needs to be incorporated into the ongoing standards work.

> This project will help the Navy to retain long-term information about marine mammal species that is needed for Navy monitoring and mitigation plans.

Work planned for 2021 will focus on the first three of the five useability enhancements: 1) technology enhancements, 2) drag-and-drop data import and 3) advanced mapping interface. A beta user group workshop, described above under key enhancement 4, was originally planned for 2021. This workshop will be deferred until 2022 due to uncertainties around COVID-19 pandemic travel restrictions.

This project will help the Navy to retain long-term information about marine mammal species that is needed for Navy monitoring and mitigation plans. As previous research has demonstrated, Tethys's data preservation and the ability to reuse data have expanded the scope of science and policy-based questions that can be asked. Retaining data from large-scale spatial and temporal studies provides clear benefits for advancing science, enhancing the Navy's capabilities for monitoring cetaceans and preparing detailed environmental impact assessments.

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 of computer science 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.

INVESTMENT AREA 5 EMERGENT TOPICS

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

There is one ongoing project summarized in this section. Progress on this project was delayed due to COVID-19 restrictions.

The ongoing project 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.

> This is critical to improving the Navy's analysis of the effects of explosive sources on marine species.

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

There will be three far-field measurement sites, arranged to characterize propagation effects.

An explosive detonation.
MC2 Josh Bennett

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

During 2019 the team procured equipment that will be needed and tested tourmaline and SoundTrap 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.

Due to COVID-19 pandemic restrictions, all planned field tests for 2020 were canceled, preventing any progress on this project. The project team will try again in 2021 to conduct field tests in coordination with Navy personnel.

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.

The two ongoing partnerships summarized in this section are

1. The Sonobuoy Liaison Working Group
2. The Subcommittee on Ocean Science and Technology Interagency Task Force on Ocean Noise and Marine Life.

Ongoing Partnerships

Sonobuoy Liaison Working Group

LMR continues to participate in and keep members of the Sonobuoy Liaison Working Group informed on the sonobuoy allocation for marine mammal research. LMR is responsible for determining which priority research projects receive available sonobuoys. For 2020, 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

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 organized to increase coordination and communication across federal agencies in addressing issues related to the potential impacts of anthropogenic noise on marine life.

Five of the SOST ITF-ONML participants—the Chief of Naval Operations Energy and Environmental 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 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 projects are presented in this report on page 53 and 55, 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, ww.navfac.navy.mil/lmr under the SOST Partnership tab.

Humpback whale.

FORECAST

We are looking forward to even more accomplishments in 2021 and beyond. Several LMR projects will be completed in 2021 and the project results, methods and technologies will become available for transition into application within the Navy's environmental compliance process and the Navy Marine Species Monitoring program.

LMR anticipates funding several projects from our Fiscal Year 2021 (FY21) Broad Agency Announcement. These new projects might include the acoustic measurement of a ship shock trial, standardizing hearing measurement methods, studying the response to new sonar signals and beginning to plan how to study behavioral response to low-frequency sonars. Selected projects will be initiated in FY21 to ensure that results and methods are available in time to be incorporated into the Navy's next environmental compliance cycle.

Looking beyond 2021, LMR will continue to meet the Navy's need for the tools and technologies necessary to sustain at-sea training and testing within environmental permit requirements. Many of these tools and technologies, which can help the Navy's Marine Species Monitoring program meet monitoring requirements in a cost-effective manner, are not readily available. This work will enable us to continue to collect marine species data and to study critical questions within a challenging oceanic environment that does not readily reveal its secrets.

To that end, we value the sustained collaboration and partnerships with other programs within the U.S. Navy—LMR, ONR and the Navy's Marine Species Monitoring program—as well as other programs, agencies and countries. Building on shared interests helps us all to more effectively leverage investments and achieve common goals.

One thing we have learned through seven years of managing the program is to be ready to adapt and address new challenges, including those posed by a worldwide pandemic. Thanks to the support of some of the greatest scientists and engineers in the field, who have demonstrated their ability to address 2020's challenges, we are optimistic about LMR's future. We will continue, in the same spirit, to adapt and 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.

PO2 Cameron Stoner

LMR Publications

Included here is a list of publications that became available in 2020 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.

A spreadsheet with all LMR publications since 2013 is now available for download at the publications tab of our website, www.navfac.navy.mil/lmr. The spreadsheet is updated quarterly.

Barlow, J., Schorr, G.S., Falcone, E.A. and Moretti, D. (2020). Variation in dive behavior of Cuvier's beaked whales with seafloor depth, time-of-day, and lunar illumination. *Marine Ecology Progress Series*, 644:199–214. DOI: 10.3354/meps13350.

Baumgartner, M.F., Bonnell, J., Corkeron, P.J., Van Parijs, S.M., Hotchkin, C., Hodges, B.A., Thornton, J.B., Mensi, B.L. and Bruner, S.M. (2020). Slocum gliders provide accurate near real-time estimates of baleen whale presence from human-reviewed passive acoustic detection information. *Frontiers in Marine Science*, February 2020. DOI: 10.3389/fmars.2020.00100.

Becker, E.A., Forney, K.A., Miller, D.L., Fiedler, P.C., Barlow, J. and Moore, J.E. (2020). Habitat-based density estimates for cetaceans in the California Current Ecosystem based on 1991–2018 survey data. *NOAA Technical Memo NMFS-SWFSC-638*.

Bouchet, P.J., Miller, D.L., Roberts, J.J., Mannocci, L., Harris, C.M. and Thomas, L. (2020). dsmextra: Extrapolation assessment tools for density surface models. *Methods in Ecology and Evolution*, 11(11). DOI: 10.1111/2041–210X.13469.

Burkard, R., Finneran, J.J., Mulsow, J. and Jones, R. (2020). Offset auditory brainstem response (ABR) amplitude in bottlenose dolphins. *The Journal of the Acoustical Society of America*, 148(3):1445–1455. DOI: 10.1121/10.0001900.

Curtis, K.A., Falcone, E.A., Schorr, G.S., Moore, J.E., Moretti, D.J., Barlow, J. and Keene, E. (2020). Abundance, survival, and annual rate of change of Cuvier's beaked whales (*Ziphius cavirostris*) on a Navy sonar range. *Marine Mammal Science*, 37(2):399–419. DOI: 10.1111/mms.12747.

Dahl, P.H., Jenkins, A. K., Casper, B., Kotecki, S.E., Bowman, V., Boerger, C., Dall'Osto, D.R., Babina, M.A. and Popper, A.N. (2020). Physical effects of sound exposure from underwater explosions on Pacific sardines (*Sardinops sagax*). *The Journal of the Acoustical Society of America*, 147(4):2383. DOI: 10.1121/10.0001064.

Finneran, J.J., Mulsow, J., Strahan, M.G., Houser, D.S. and Burkard, R.F. (2020). Role of the temporal window in dolphin auditory brainstem response onset. *The Journal of the Acoustical Society of America*, 148(5):3360–3371. DOI: 10.1121/10.0002703.

Fregosi, S., Harris, D.V., Matsumoto, H., Mellinger, D.K., Negretti, C., Moretti, D.J., Martin, S.W., Matsuyama, B., Dugan, P.J. and Klinck, H. (2020). Comparison of fin whale 20 Hz call detections by deep-water mobile autonomous and stationary recorders. *The Journal of the Acoustical Society of America*, 147(2):961 (2020). DOI: 10.1121/10.0000617.

Fregosi, S., Harris, D.V., Matsumoto, H., Mellinger, D.K., Barlow, J., Baumann-Pickering, S. and Klinck, H. (2020). Detections of whale vocalizations by simultaneously deployed bottom-moored and deep-water mobile autonomous hydrophones, *Frontiers in Marine Science*, 7. DOI: 10.3389/fmars.2020.00721.

Hansen, K.A., Hernandez, A., Mooney, T.A., Rasmussen, M.H., Sørensen, K. and Wahlberg, M. (2020). The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. *The Journal of the Acoustical Society of America*, 147(6):4069. DOI: 10.1121/10.0001400.

These publications are of great value to the Navy's at-sea environmental compliance process.

Helble, T.A., Guazzo, R.A., Alongi, G.C., Martin, C.R., Martin, S.W. and Henderson, E.E. (2020). Fin Whale Song Patterns Shift Over Time in the Central North Pacific. *Frontiers in Marine Science*, 7. DOI: 10.3389/fmars.2020.587110.

Helble, T.A., Guazzo, R.A., Martin, C.R., Durbach, I.N., Alongi, G.C., Martin, S.W., Boyle, J.K. and Henderson, E.E. (2020). Lombard effect: Minke whale boing call source levels vary with natural variations in ocean noise. *The Journal of the Acoustical Society of America*, 147(2):698–712. DOI: 10.1121/10.0000596.

Isojunno, S., Wensveen, P.J., Lam, F-P.A., Kvadsheim, P.H., von Benda-Beckmann, A.M., Martín López, L.M., Kleivane, L., Siegal, E.M. and Miller, P.J.O. (2020). When the noise goes on: received sound energy predicts sperm whale responses to both intermittent and continuous navy sonar. *Journal of Experimental Biology*, 223(7):jeb219741. DOI: 10.1242/jeb.219741.

Kastelein, R.A., Helder-Hoek, L., Cornelisse, S.A., Huijser, L.A.E. and Gransier, R. (2020). Temporary hearing threshold shift at ecologically relevant frequencies in a harbor porpoise (*Phocoena phocoena*) due to exposure to a noise band centered at 88.4 kHz. *Aquatic Mammals*, 46(5):444–453, DOI: 10.1578/AM.46.5.2020.444.

Kastelein, R.A., Parlog, C., Helder-Hoek, L., Cornelisse, S. A., Huijser, L.A.E. and Terhune, J.M. (2020). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 40 kHz. *The Journal of the Acoustical Society of America*, 147(3):1966–1976. DOI: 10.1121/10.0000908.

Kastelein, R.A., Parlog, C., Helder-Hoek, L., Cornelisse, S. A., Huijser, L.A.E. and Terhune, J.M. (2020). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 32 kHz. *The Journal of the Acoustical Society of America*, 147(3):1885–1896. DOI: 10.1121/10.0000889.

Mooney, T.A., Smith, A.B., Larsen, O.N., Hansen, K.A. and Rasmussen, M. (2020). A field study of auditory sensitivity in the Atlantic puffin, *Fratercula arctica*. *Journal of Experimental Biology*, 223(15). DOI: 10.1242/jeb.228270.

Varghese, H.K., Miksis-Olds, J., DiMarzio, N., Lowell, K., Linder, E., Mayer, L. and Moretti, D. (2020). The effect of two 12 kHz multibeam mapping surveys on the foraging behavior of Cuvier's beaked whales off of southern California. *The Journal of the Acoustical Society of America*, 147(6):3849–3858. DOI: 10.1121/10.0001385.
(Note: This project, though not funded by the LMR program, used data from the Marine Mammal Monitoring on Ranges [M3R] system developed under projects funded by the LMR and Office of Naval Research Marine Mammal Biology programs.)

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
BAA .....Broad Agency Announcement
BOEM .....Bureau of Ocean Energy Management
BRS .....Behavioral Response Study
CAD .....Computer-aided design
CAS .....Continuously active sonar
CEE .....Controlled exposure experiment
CENRS .....Committee on the Environment, Natural Resources, and Sustainability
CREEM .....Centre for Research into Ecological and Environmental Modelling
CSEE .....Coordinated sonar exposure experiments
CT .....Computerized tomography
DCLT .....Detection, classification, localization, and tracking
DICASS .....Directional command activated sonobuoy system
DenMod .....Density Surface Modeling (project)
DTAG .....Digital acoustic recording tag
EDA .....Effective detection area
EIS .....Environmental Impact Statement
ESA .....Endangered Species Act
GPL .....Generalized Power Law
GPS .....Global positioning system
HMM .....Hidden Markov model
HPN .....High-pass noise
HSTT .....Hawaii-Southern California Testing and Training Ranges
ICI .....Inter-click interval
ICMP .....Integrated Comprehensive Monitoring Plan
ITF-ONML .....Interagency Task Force on Ocean Noise and Marine Life
IPR .....In-progress Review
ISO .....International Organization for Standardization
kHz .....kilohertz
LIMPET .....Low Impact Minimally Percutaneous External-electronics Transmitter
LMR .....Living Marine Resources
LMRAC .....Living Marine Resources Advisory Committee
M3R .....Marine Mammal Monitoring on Navy Ranges
MARMAM .....Marine Mammals Research and Conservation Discussion (University of Victoria email list)
MFAS .....Mid-frequency active sonar
MMC .....Marine Mammal Commission
MMPA .....Marine Mammal Protection Act
MOCHA .....Multi-study Ocean Acoustics Human Effects Analysis
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
NCEI .....National Centers for Environmental Information
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
PAM .....Passive acoustic monitoring
PAM-DE .....PAM-based density estimation
PAS .....Pulsed active sonar
PCoD .....Population consequences of disturbance
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
SCORE .....Southern California Offshore Range
SCR .....Spatial Capture Recapture
SEL .....Sound exposure levels
SMRT .....Sound and motion recording and telemetry
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
UUV/UAV .....Unmanned underwater vehicle/ underwater autonomous vehicles
VHF .....Very high frequency
VLA .....Vertical line array
WHOI .....Woods Hole Oceanographic Institution
µCT .....Computed microtomography

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