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NOAA
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Ocean Noise Strategy Roadmap

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INTRODUCTION

Increasing human activity, along more of the earth's coastlines and extending farther offshore in deep ocean environments, is leading to rising levels of anthropogenic underwater noise. Increasing noise levels are impacting the animals that inhabit these places in complex ways and their ecosystems, including through acute, chronic, and cumulative effects. In the U.S., the National Oceanic and Atmospheric Administration (NOAA) is the federal agency that is most responsible for protecting aquatic animals and their habitats, through a variety of legal mandates. NOAA's approach towards further understanding and managing underwater noise should be multi-faceted. Numerous studies illustrate specific adverse physical and behavioral effects that exposure to certain noise types and levels can have on different species. Additionally, sound is a fundamental component of the physical and biological habitat that many aquatic animals and ecosystems have evolved to rely on over millions of years. In just the last ~100 years human activities have caused large increases in introduced noise and changes in soundscapes.[1] These changes can lead to reduced ability to detect and interpret acoustic cues that animals use to select mates, find food, maintain group structure and relationships, avoid predators, navigate, and perform other critical life functions. Therefore, NOAA's management goals and actions should aim to address chronic effects and conserve the quality of acoustic habitats[2] in addition to minimizing more acute adverse physical and behavioral impacts on specific species.

Here, we present the NOAA Ocean Noise Strategy (the 'Strategy') Roadmap. This document is designed to support the implementation of an agency-wide strategy for addressing ocean noise over the next 10 years. The Roadmap highlights a path to expand NOAA's historical focus on protecting specific species by additionally addressing noise impacts on high value acoustic habitats[3]. Fundamentally, the Strategy Roadmap serves as an organizing tool to rally the multiple NOAA offices that address ocean noise impacts around a more integrated and comprehensive approach. A series of key goals and recommendations are presented that would improve NOAA's ability to manage both species and the places they inhabit in the context of a changing acoustic environment. The Strategy Roadmap is not intended to be a prescriptive listing of program-level actions. Instead this document is intended to provide a cross-line office roadmap summarizing some of the essential steps that could be taken across the agency to achieve the Strategy's goals for more comprehensive management of noise impacts.

The information and guidance included in the Roadmap can strengthen the abilities of regulatory and science programs addressing noise impacts (including those with noise-producing operations) to meet their existing strategic goals and plans. Some recommendations suggest actions that could be taken by individual programs within the agency, while others highlight opportunities for parallel activity or partnerships among multiple programs. Crafting and implementing modernized management approaches that balance competing needs of lawful commercial, economic, scientific, national defense and security activities, protected species, and natural acoustic habitats will continue to present NOAA significant challenges over the coming decade. The recommendations outlined in the Roadmap suggest

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[1] International Standards Organization 12913-1:2014: "The standard distinguishes the perceptual construct (soundscape) from the physical phenomenon (acoustic environment), and clarifies that soundscape exists through human perception of the acoustic environment." In practice, however, wildlife ecologists have defined soundscapes as the sound present in a particular location and time, considered as a whole.

[2] Distinguishable soundscapes inhabited by individual animals or assemblages of species, inclusive of both the sounds they create and those they hear.

[3] See Chapter 2

cross-agency actions that would put NOAA on the path to meeting these challenges and achieving the goals of the Strategy. It is important to note that in addition to conserving marine resources, NOAA's mandates include permitting impacts to marine species and their habitat, including impacts from noise, provided those impacts are not too severe and appropriate protective measures are included. NOAA implements these responsibilities via authorizations, consultations, and other mechanisms, and incorporates a variety of protective measures to minimize the impacts of noise. The Strategy aims to further ensure that NOAA is addressing these broader goals as effectively as possible across multiple actions and programs, and that the agency is targeting the science and stakeholder engagement necessary to support its diverse responsibilities.

HISTORY AND DEVELOPMENT OF OVERARCHING GOALS

In 2010, NOAA leadership committed to improving the tools used by the agency to evaluate the impacts of anthropogenic noise on cetacean species. This led to the convening of two parallel data- and product-driven working groups collectively known as "CetSound" (Cetaceans and Sound Mapping). The CetSound working groups: (1) created a new cetacean density and distribution data visualization and exploration tool, and; (2) predicted wide-ranging, long-term underwater noise contributions from multiple human activities. In 2012, the geospatial tools developed by these working groups were presented to a large audience representing a diversity of stakeholders. Following the broadly positive reception of the tools, NOAA leadership encouraged the development of a 10-year Ocean Noise Strategy to guide the agency to a more integrated and comprehensive management of ocean noise impacts.

Staff and leadership from NOAA Fisheries' Offices of Protected Resources and Science and Technology and the National Ocean Service's Office of National Marine Sanctuaries identified ***four overarching goals*** the Strategy aims to achieve:

1. SCIENCE: NOAA and federal partners are filling shared critical knowledge gaps and building understanding of noise impacts over ecologically-relevant scales
2. MANAGEMENT[4]: NOAA's actions are integrated across the agency and minimizing the acute, chronic and cumulative effects of noise on marine species and their habitat
3. DECISION SUPPORT TOOLS: NOAA is developing publically available tools for assessment, planning and mitigation of noise-making activities over ecologically-relevant scales
4. OUTREACH: NOAA is educating the public on noise impacts, engaging with stakeholders & coordinating with related efforts internationally

In order to advance a 10-year strategy to accomplish this vision, in 2013 NOAA leadership solicited participation in a cross-NOAA team (see Appendix D) that would encompass a diverse group of scientific experts, regulatory practitioners, managers, and lawyers who are knowledgeable in the field of ocean noise and represent multiple programs or authorities through which NOAA regulates, researches, or produces ocean noise. Participants identified the need for a roadmap document to articulate the goals of the Strategy and to suggest approaches for achieving a more integrated and comprehensive understanding and management of ocean noise impacts. A subset of participants (see Appendix D) then

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[4] The term "management" refers here to all NOAA actions that seek to reduce or eliminate impacts to trust resources (i.e. species, stocks, habitats and areas under NOAA's purview). Such actions include a variety of methods by which individual NOAA programs implement their long-term strategic plans, including, but not limited to, activity-specific regulation of impacts to individual species and stocks, prioritization of internal capacities, providing regional, national and international leadership or coordination of protective actions, and providing recommendations or guidance to other federal and state agencies.

drafted the Ocean Noise Strategy Roadmap. The draft Roadmap was circulated in 2015 first among all Strategy participants, and then more broadly within the line offices they represented. In addition, Strategy leads provided informational briefings and distributed the document to additional NOAA programs that had potential interest in the initiative but that did not identify staff to participate in the drafting.

OCEAN NOISE STRATEGY ROADMAP

The purpose of the NOAA Ocean Noise Strategy Roadmap is to support the agency's use of its capabilities and authorities to more effectively understand and address the effects of noise on protected species *and* acoustic habitats. Four chapters address key elements of the Strategy's approach and provide place-based examples:

Chapter 1: Reviewing *species level* impacts of ocean noise and associated management actions
Chapter 2: Establishing the foundation for understanding and managing *acoustic habitats* for NOAA trust species and places
Chapter 3: Reviewing NOAA's current capability to *characterize aquatic soundscapes* and enhancing this capacity for the future
Chapter 4: Applying *risk assessment* to place-based examples that highlight Roadmap science and management recommendations

Chapter 1 (Reviewing *species level* impacts of ocean noise and associated management actions) with associated Appendices, summarizes the status of the science needed to understand, characterize, and manage the effects of noise across NOAA's protected species. The Chapter outlines and summarizes historical approaches to noise management, and presents recommendations for improved approaches moving forward. The Chapter highlights the current status of and need for methodological approaches to determine population level and cumulative consequences to NOAA resources. NOAA's authorities for addressing noise impacts on managed species and their identified habitats are then summarized, and current practices for applying these authorities are described. The Chapter identifies high priority science, risk assessment, and management examples to increase the effectiveness of NOAA's current management practices to address chronic and cumulative noise impacts, and broaden practices to better address impacts to sea turtles, fish and marine invertebrates. Additional detail is provided in the associated Appendices. Appendix A outlines the status of science regarding sound use by, and noise impacts to, four broad taxonomic groups for which NOAA has different management responsibilities: marine mammals, fish, invertebrates, and sea turtles. Appendix B summarizes the status of information regarding presence, abundance, distribution, density, habitat use, and population trends for these species.

Chapter 2 (Establishing the foundation for understanding and managing *acoustic habitats* for NOAA trust species) presents the basis for the development of an agency-wide strategy to more comprehensively manage noise impacts on acoustic habitats. NOAA's place-based management tools are examined to consider their application to acoustic habitat protection goals, highlighting activities that are underway or could be undertaken to achieve these goals. Recommended activities include: 1) partnerships with regulated federal agencies and industries to address longer-term and wider-ranging noise impacts via promotion of quieter technologies; 2) development of tools and application to marine planning and traditional protected species management efforts to account for cumulative noise within places where acoustically active or sensitive species live; and 3) fulfilling the current potential of existing NOAA authorities to address noise implications within areas with more holistic protective goals, such as National Marine Sanctuaries. Throughout, information needs for NOAA's identification of high risk acoustic habitats are discussed, including implications for broadening the focus of noise-related research to better characterize habitat status and noise influence as mediated through entire ecosystems.

Chapter 3 (Reviewing NOAA's current capability to *characterize aquatic soundscapes* and enhancing this capacity for the future) addresses the science needs highlighted in Chapters 1 and 2 that suggest a need for the agency to augment its capacity to effectively understand and accurately characterize soundscapes and the component sounds that comprise them. Soundscapes can be characterized through the use of a range of both fixed and mobile equipment platforms to collect acoustic data. Acoustic analyses can include measurement of both specific sounds over short time frames, to broader quantifications of the multiple component sounds and overarching variability inherent in a soundscape or acoustic habitat. In addition, in the absence of empirical data, the use of predictive sound field modeling to assess the likely acoustic contribution of anthropogenic sources in various human-use scenarios plays a key role in meeting NOAA's science and management goals. Offices across NOAA are increasingly utilizing a variety of fixed and mobile platforms to collect acoustic data to study the ecology and behavior of marine animals, ambient ocean noise, geophysical events, as well as anthropogenic noise that could affect marine life. To support and continue this expansion in NOAA's passive acoustic research capability, the Roadmap recommends strategic coordination among research programs, development of a standardized data and metadata archival system and analysis routines, and increased predictive modeling capacity to achieve the Strategy's science and management priorities.

Chapter 4 (Applying *risk assessment* to place-based examples that highlight Roadmap science and management recommendations) presents two place-based case studies that highlight the Roadmap's science and management recommendations within a risk assessment process. Risk assessment can integrate information regarding soundscapes and the places and species the agency manages in order to identify priorities for noise management. Results can inform NOAA's decision-making regarding allocation of limited agency resources to address data gaps. Finally, risk assessment can support choices regarding which management approaches to apply as well as highlighting the need for enhanced authorities or partnerships, and provide mechanisms for evaluating the success or failure of various approaches. The first case study applies risk assessment processes to examine noise impacts to fin, blue and humpback whales in and around Channel Islands National Marine Sanctuary. The second case study provides a preliminary assessment of spawning areas used by acoustically sensitive and commercially important fishes off the U.S. East Coast. These case studies identify current or potential NOAA assets for assessing noise risks and managing noise impacts, highlighting partnerships that are in place or could be further developed to address Roadmap recommendations for science, management and outreach.

SUMMARY OF OVERARCHING AND CROSSCUTTING RECOMMENDATIONS

Chapters 1-3 include recommendations for steps NOAA could take to achieve the Strategy goals. A summary table of these recommendations follows, categorized by the primary Strategy goal each action addresses and the key chapter(s) in which it appears. Relevance to multiple Strategy goals is identified for some recommended actions. These recommended actions would improve understanding and management of the species and habitats under NOAA's care and utilize the diverse expertise within the agency to more comprehensively address the impacts of noise.

Primary Strategy Goal	Recommendation	Key Chapters	Additional Goals Addressed
Management: Expanding types of, scopes of, and coordination among NOAA authorities to address noise issues		1,2	
	Identification and utilization of a full range of NOAA authorities to better manage the impacts of noise on trust resources	1,2	
	Development of national guidance for acoustic impact thresholds and other management tools	1	
	Increased use of programmatic approaches through MMPA and ESA to allow for better consideration of multiple activities, longer timeframes, and acoustic habitat impacts	1,2	
	Improving management effectiveness for acoustic habitat through incorporation of place-based authorities as they relate to species or habitat focused goals	2	
	Utilization of National Marine Sanctuaries to develop increased capacity for preserving, restoring, and maintaining natural acoustic habitats, as well as the protected species associated with them, through new management measures, regulations, dedicated scientific research, and outreach programs	2	Science; Outreach
	Expansion of existing international partnerships with regulated agencies and industries to promote use of quieter technologies	2	Science; Outreach
Science and Monitoring: Development of comprehensive and forward-looking science plans identifying most effective and efficient means to address critical data needs for understanding noise impacts on protected species and acoustic habitats		1,2,3	Management
	Establishment of a NOAA-led, long-term, standardized and calibrated acoustic monitoring network across the agency	3	Management
	Development of an archival database to house NOAA passive acoustic metadata, raw data, and outputs of standardized data analysis routines	3	Tools
	Enacting monitoring requirements for compliance processes that reflect comprehensive science goals, and further identifying actions that may be taken at different scales to address varying resources and capabilities	1	Management
Decision Support Tools and Services: Development of processes and tools to compile, geospatially depict, and analyze marine species distributions, soundscapes, and NOAA-permitted/authorized activities for use in risk assessment, mitigation development and planning.		1,2,3,4	Management; Science; Outreach
	Developing NOAA 'in-house' capacity for predictive sound field and sound exposure modeling	1,3	Management; Science; Outreach
	Standardization of data analysis routines and output metrics for soundscape measurements	3	Science; Outreach
Outreach, Collaboration, and Stakeholder Engagement: Further development of outreach programs to support the activities outlined above		1,2	Management; Science; Tools

The NOAA Ocean Noise Strategy and Managed Species

INTRODUCTION

There are a number of human activities that can introduce potentially detrimental levels of sound into the aquatic environment (see Chapter 3), affecting a wide range of acoustically sensitive animals. Many of these human-made sounds are incidental to the purpose of the activity, such as the intense impulsive sounds produced during pile driving with impact hammers or the lower level continuous sounds produced by vessel traffic. Other sounds are an integral and necessary part of the activity, such as the sounds produced by active sonar or the impulsive sounds generated by seismic airguns used for oil and gas exploration or research. All of these activities can potentially affect the animals present in the ensonified area (the area in which the sound is detectable above other sounds), some of which are federally managed as protected species. Potential effects range from none to altering important behavioral patterns, masking, hearing impairment, habitat abandonment, or even death, in certain circumstances.

Sound is often of critical importance to aquatic fauna, not only for purposeful communication with conspecifics, but also in the detection of predators and prey, and for navigation and other purposes. Competing sounds that interfere with the detection or interpretation of these important cues can result in detrimental effects to aquatic species utilizing a given "acoustic habitat" (see Chapter 2[5]). Sounds utilized for purposes other than communication span frequency ranges beyond those used in vocalizations. Of growing concern is the need to address the chronic (persistent/longer-term) and aggregated or cumulative effects of rising noise levels resulting from increased human activities across multiple sectors, industries, and federal agencies.

More commonly known and historically addressed through NOAA's existing authorities are the direct or acute (i.e., of rapid onset and shorter duration) physical, physiological, and behavioral impacts that noise exposure can have on marine fauna. These effects are often addressed in the context of a single activity and include hearing impairment (i.e. permanent or temporary threshold shift, see Appendix A), tissue damage, or behavioral disturbance of varying degrees and outcomes (e.g., vocalization changes, migration deflection, avoidance of areas, feeding disruptions). Adverse stress responses, which can have acute and/or chronic effects, have not typically been comprehensively addressed. All of the aforementioned effects, acute and chronic, in certain circumstances and in combination with one another, can translate to adverse health or energetic effects that can ultimately lead to reduced survival, growth or reproductive success of individuals with potentially adverse population impacts.

Through the Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), Magnuson-Stevens Conservation and Management Act (MSA), and the National Marine Sanctuaries Act (NMSA), NOAA is responsible for the management of all but a small number of marine mammals, all sea turtles, ESA-listed fish and invertebrates, many commercially important fish and significant marine areas. Examples of the effects described in previous paragraphs are known across many marine taxa including marine mammals, fish, invertebrates, and sea turtles. Management and science actions related to noise effects have been more heavily publicized and highlighted for marine mammals and this document seeks to highlight the need to better address the impacts of underwater noise on other taxa, many of the

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[5] All of the sound present in a particular location and time, considered as a whole, comprises a "soundscape" (Pijanowski et al. 2011). When examined from the perspective of the animals experiencing it, a soundscape may also be referred to as "acoustic habitat" (Clark et al. 2009, Moore et al. 2012a, Merchant et al. 2015).

examples in this Chapter are specific to marine mammals because of the information available – but the concepts are still often applicable to other taxa.

Through this NOAA Ocean Noise Strategy Roadmap document (Roadmap) and in support of the overall Strategy, NOAA seeks to focus and guide the agency's capabilities and authorities to more effectively address the effects of noise on protected species (meaning the taxa indicated above that are managed under NOAA's authorities) and habitats. NOAA has programs that regulate impacts (including those from noise) on protected species and their habitat, programs that gather data and conduct research related to noise and protected species, and programs that produce underwater noise during the course of their normal operations and duties (e.g., NOAA's use of active scientific sonar sources in the course of fisheries research). In addition to providing new focus on the importance of addressing the chronic and aggregate effects of rising noise levels on acoustic habitat, NOAA also aims to identify and agency actions to better address the acute, direct physical and behavioral effects of noise exposures to individuals and their ultimate effects on the populations. We specifically draw attention to the following additional three needs: (1) better understanding of how noise impacts on individuals can translate to population level effects; (2) better understanding of the aggregated effects, on individuals and populations, of multiple noise sources and cumulative effects of noise combined with other stressors; and (3) broadening NOAA's practices to better address impacts to fish, invertebrates, and sea turtles.

This Chapter (and associated Appendices) is organized in the following manner:

- In the "Building Blocks of Impact Assessment" section and Appendices A and B, we summarize the status of the science as it relates to the categories of information needed to understand, characterize, and manage the effects of noise across four broad taxa for which NOAA has different management responsibilities: marine mammals, fish, invertebrates, and sea turtles.
- In the "Evaluating Population-level and Cumulative Effects of Noise" section, we briefly describe the challenges of evaluating chronic effects and stress, and also include several examples of methodological approaches that can be used to evaluate population level and aggregate noise consequences to NOAA resources.
- In the "Current NOAA Management of Noise Impacts" section, we identify the management authorities through which NOAA can address the effects of human-produced noise on these specific taxa, as well as acoustic habitat. The "Regulatory and Analytical Approaches" section briefly describes some current strategies for implementing these authorities.
- Last, in the "Next Steps for the NOAA Ocean Noise Strategy" section, we identify some high priority science, risk assessment, and management needs intended to guide NOAA actions for addressing noise impacts to all four of these acoustically sensitive taxa and their acoustic habitat.

THE BUILDING BLOCKS OF IMPACT ASSESSMENT

In order to begin to characterize, predict, assess, and manage the potential effects of specific activities that generate underwater sound on an acoustically sensitive animal and its habitat, certain key information is needed: where species are located, how they use sound, and the known effects of noise on that species. Additionally, understanding critical data gaps helps inform science and monitoring priorities. **Appendix A: The Status of Science Needs for Assessing Noise Impacts to NOAA-Managed Species** outlines the status of science regarding sound use by, and noise impacts to, four broad taxonomic groups for which NOAA has different management responsibilities: marine mammals, fish, invertebrates, and sea turtles. **Appendix B: Presence, Abundance, Distribution, Density, Habitat Use, and Population Trends** summarizes the status of information regarding presence, abundance, distribution, density, habitat use, and population trends for these species. We summarize some major points from the Appendices below.

Sound Use and Production

Marine mammals have been more extensively studied than other marine fauna in terms of their hearing sensitivities and absolute hearing thresholds (though less so for mysticetes), as well as their vocalizations. Marine mammals both produce, and use, sounds spanning a wider range of frequencies and decibel levels than other marine taxa, and they use them for a wide variety of purposes. Further, some of the more subtle aspects of hearing in marine mammals such as frequency discrimination, localization ability, and critical ratios have been studied. Fishes are the largest and most diverse vertebrate group, and while we are aware of many adaptations that allow them to both detect and produce sounds for a variety of purposes, there is much that is still unknown. We do know, though, for example, that some fishes are able to detect sound pressure and can hear and determine the direction of sound via particle motion. Also, the presence and location of a swim bladder relative to the ear in fishes may affect the degree of hearing sensitivity as well as the susceptibility of sustaining physical injury to the body when exposed to certain sound pressure levels. Although invertebrates have been studied less than marine mammals and fish, we know that some invertebrates are capable of detecting vibrations and others may detect particle motion and even sound pressure (Budelmann 1992, Popper et al. 2001, Kaifu et al. 2008). Some invertebrates also produce sounds, or use sound for orientation and stunning of prey. Sea turtle hearing and use of sound have not been well studied and sea turtles are not known to intentionally produce sounds underwater. While a few studies document the use of sound to detect important environmental cues, sea turtles are not thought to produce sound for particularly directed purposes, such as communication.

Impacts of Noise

Studies of the impacts of noise on marine mammals are numerous and cover a wide range of species, sound sources and characteristics, environments (laboratory and field), and observed effects. Documented impacts range from none, to behavioral disturbance (avoidance, vocalization changes, changes in swim speed and direction, alarm responses), adverse stress responses, masking, hearing impairment (temporary or permanent), tissue damage, and death. Studies on fish have focused more on characterizing the physical effects such as hearing impairment, barotrauma, and death, but behavioral effects such as changes in direction, speed, or schooling patterns as well as changes in stress hormones have been documented. Unlike in marine mammals, hearing impairment is considered recoverable in fishes because many of the species that have been researched indicate they can grow back their hair cells. However, there remains much that is unknown about hearing in fishes and the ability to recover from hearing damage because of the great number of fish species that have not been studied. Less research has been conducted on invertebrates, but some research on cephalopods has indicated high intensity low frequency sounds, as well as long exposures to continuous sounds, may damage the hair cells in their statocysts, which could inhibit their ability to perform important life functions, although behavioral studies that would support such conclusions have not been conducted. Fewer targeted studies document the impacts of noise on sea turtles. Some studies have documented multiple types of changes in behavior in response to a few sound sources, but other studies have documented no changes. For all taxa, the focus is expanding to better understand the effects of changes in the soundscape.

Species Presence, Abundance, and Distribution

A key building block of risk assessment is reliable information on the potentially impacted species or stock presence, abundance and distribution, both spatially and seasonally. Select species have been well studied in certain areas and seasons. Appendix B outlines where available abundance and distribution data may be accessed, as well as other important information on habitat use and life history. However, there is a lack of adequate abundance and distribution information for most protected species. For example, NOAA is mandated to collect stock assessment data for protected species and the agency has developed a systematic method for ranking the adequacy of stock assessments. For marine mammals, only about 17% of the marine mammal stocks NOAA Science Centers track and collect data for are considered to have adequate assessments and about 47% of the stocks have either never had an assessment conducted, or the last one was over 10 years ago. About 34% of ESA-listed fish are considered to have adequate stock assessments. None of NOAA's ESA-listed invertebrate species (coral and abalone) or sea turtle species are considered to have adequate assessments. NOAA is constantly working to maximize the effectiveness of stock assessment data collection within given resource availability.

Characterization of Human Introduced Sounds

Understanding the characteristics of sound sources and noise-producing activities is an important part of impact assessment and is discussed in Chapter 3. Some examples of activities or types of human-made sound that may have the potential to adversely impact marine fauna acutely and/or chronically include: vessel noise (offshore and nearshore - commercial and recreational vessels); active sonar (military and research activities); seismic airguns (for oil and gas exploration and research); underwater explosives (military operations, harbor deepening, fishing deterrents, and rig removal); pile driving (impact and vibratory); renewable energy sources (e.g., wind, wave, and tidal farms); acoustic deterrents; dredging; icebreaking; drilling, and; rocket launches.

EVALUATING POPULATION-LEVEL AND CUMULATIVE IMPACTS OF NOISE

Beyond some of the basic pieces of impact assessment addressed above, we highlight here some of the more challenging components of understanding the impacts of noise on marine fauna, as well as some emergent methodologies that are currently being applied. Specifically we discuss the difficulty of assessing stress and chronic effects and the shortage of needed data to do so. Further, we discuss an emerging quantitative framework for addressing the need to better characterize and predict how acute and chronic disturbance effects can translate to effects on individual fitness and populations. Last, we look at some analytical examples of where data and modeling have been used to assess the effects of both the aggregated sounds of multiple activities, as well as noise in combination with other stressors. Several of the examples relate specifically to marine mammals (because that is what is available), but have broader applicability as well.

Stress

Adverse stress responses are one in a suite of potential effects that should be addressed when evaluating the impacts of noise on an individual or population. We highlight adverse stress responses here because while data indicate that they can have serious consequences to individuals, they have been largely under-represented in impact assessments, likely because of the complexity of detecting these responses in wild populations and the lack of adequate baseline stress-marker datasets to which field measurements can be compared to appropriately assess context and significance.

The Office of Naval Research's (ONR) Marine Mammals and Biology Program has several major research interest areas or thrusts, including better understanding the Effects of Sound on Marine Life topic, which aims to better understand and characterize the behavioral, physiological (hearing and stress response), and potentially population-level consequences of sound exposure on marine life. Physiological Stress

Responses is one of the specific thrusts of the Effects of Sound on Marine Life program (http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology/Marine-Mammal-Biology-Thrusts.aspx). ONR's 2014 annual report (Cockrem 2014) compiles information from 239 papers or book chapters relating to stress in marine mammals. While these articles were marine-mammal specific, some of the information is also more broadly applicable to other marine vertebrate taxa, for which there is even less data available.

Cochrem (2014) explains that animals are continuously aware of and respond to changes in their environment and when physical or social stimuli are threatening or harmful, then neural and neuroendocrine pathways are activated and a stress response is initiated. These threatening or potentially harmful changes in the environment (or perceived to be threatening or harmful), which can either require cognitive appraisal or be completely physical (i.e., temperature), are termed stressors (Cochrem 2014). A stress response occurs when a stressor activates the neuroendocrine stress system (NSS), resulting in glucocorticoid (cortisol or corticosterone) release from the adrenal cortex (Cochrem 2014). A stress response can last from minutes to hours, and includes increased sympathetic nervous system activity and a rapid and transient release of catecholamines from the adrenal medulla (Cochrem 2014). While we typically focus on adverse stress responses, stress responses are part of a natural process to help animals adjust to changes in their external or internal environment (maintain homeostasis), and can also be either beneficial or neutral.

Although extensive terrestrial vertebrate datasets illustrate that the impacts of chronic stress effects can adversely impact individuals through immune suppression, inhibition of other hormonal systems, and the disruption of reproductive function, such studies within marine systems remain rare. In a unique circumstance, (Rolland et al., 2012) suggested evidence of a reduction in stress hormone levels associated with reduced exposure of North Atlantic right whales to noise from large commercial vessels. Laboratory studies showing explicit stress responses to noise and field noise measurements have increased our ability to compare hormone levels with other potentially causative variables. However, there are no large cross-sectional datasets of stress markers in free-ranging marine populations, which means that we lack an understanding of natural variation within individuals based on sex, age, and reproductive status. Further, we don't fully understand the relationship among various hormones and the quantitative differences to be expected among sample types (e.g., blood, blubber, feces) in free-ranging individuals. Because of this, there is a current inability to interpret context and the biological significance of variation in stress markers in individuals.

Acoustic Habitat Effects

Earlier in this Chapter we referenced NOAA's augmented focus to ensure that the chronic effects of rising noise levels on the acoustic habitat of protected species (i.e., the masking of important species-specific acoustic cues) are better addressed through the agency's efforts. While these types of effects are touched on in Appendix A, Chapter 2 describes these effects in detail and recommends management and science actions to better address them.

Population Effects

Because of the methodological challenges (including difficulty identifying all of the contributing variables), as well as the time and resource commitment necessary, few studies have quantified the ultimate impacts to marine mammal populations associated with disturbance from noise or other causes. Lusseau and Bejder (2007) present data from three long-term studies illustrating the connections between disturbance from whale-watching boats and population-level effects in cetaceans. Across these three multi-year studies, the effects of increased boat traffic from tourism ranged from a

15% decrease in abundance (Shark Bay Australia, bottlenose dolphins, Bejder et al., 2006), a transition from a short-term avoidance strategy to long-term displacement resulting in reduced reproductive success and increased stillbirths (Fiordland New Zealand, bottlenose dolphins, Lusseau 2004), to decreased foraging opportunities and increased traveling time that a simple bioenergetics model equated to decreased energy intake of 18% and increased energy output of 3-4% (Vancouver Island Canada, northern resident killer whale, Williams et al., 2006). These studies are presented because of the lack of similar studies for other activity types, not because of an enhanced concern for whale watching above other activity types. In fact, Weinrich and Corbell (2009) report that the reproductive success of female humpback whales was not affected by whale watching exposures in southern New England.

In order to understand how the effects of activities to individual marine animals may or may not impact stocks and populations, it is necessary to understand not only what the likely disturbances are going to be, but how those disturbances or other impacts may affect the reproductive success and survivorship of individuals, and then how those impacts to individuals translate to population changes. As noted above, one of the major interest areas for the Office of Naval Research's (ONR) Marine Mammals and Biology Program is better understanding the population-level consequences of sound exposure on marine life. Following on the earlier work of a committee of the U.S. National Research Council (NRC 2005), ONR has funded the Potential Consequences of Acoustic Disturbance (PCAD) effort from 2009-2015, which included four working group case studies and was modified to the Potential Consequences of Disturbance (PCoD) to allow for the consideration of more data using other disturbance types as surrogates for noise in the case studies. Supported by the PCoD effort, New et al. (2014) outline an updated conceptual model of the relationships linking disturbance to changes in behavior and physiology, health, vital rates, and population dynamics (see Figure 1-1). While this effort targets marine mammals, this conceptual model is likely broadly applicable in illustrating the potential pathways from individual disturbances to population-level impacts for other taxa.

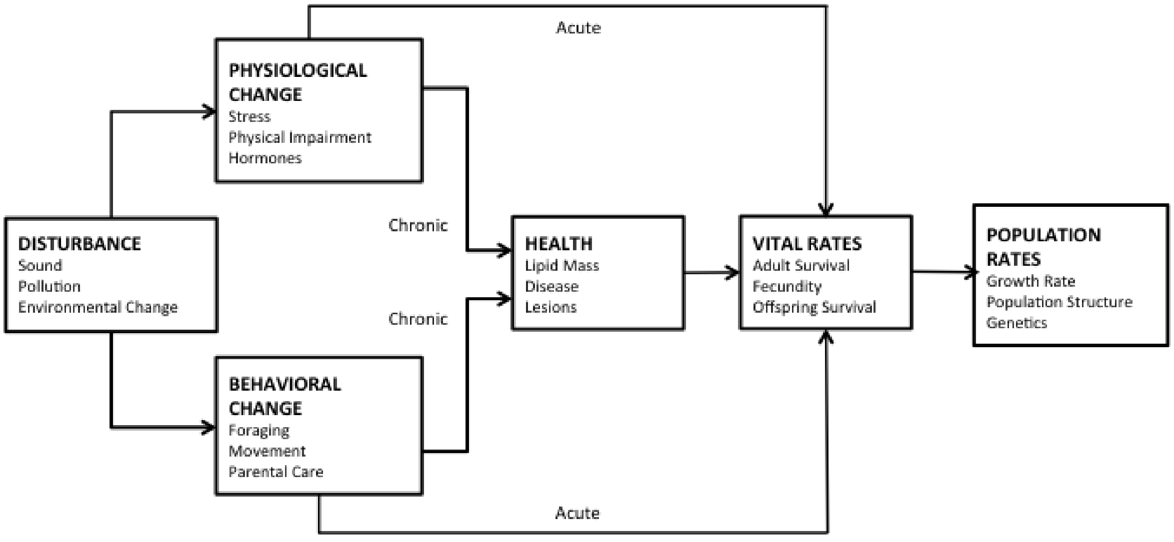

Figure 1-1. Potential Consequences of Disturbance conceptual model of the relationships linking disturbance to changes in behavior and physiology, health, vital rates, and population dynamics (New et al., 2014).

As described in the PCoD model, adverse behavioral and physiological changes resulting from disturbance (stimulus or stressor) can either have acute or chronic pathways of affecting vital rates (Figure 1-1). For example, acute pathways can include changes in behavior or habitat use, or increased stress levels that directly raise the probability of mother-calf separation or predation. Chronic effects on vital rates occur when behavioral or physiological change has an indirect effect on a vital rate that is mediated through changes in health over a period of time, such as when adverse changes in time/energy budgets affects lipid mass, which then affects vital rates (New et al., 2014). New et al. outline this general framework, compile the relevant literature that supports it, and include specific examples of types of behavioral, physiological and biological changes, health effects, vital rates and population rates (within each box, above) for which there are data illustrating the connections between these stages of effects for certain species and situations. Further, these authors, and others involved in the PCoD effort, have developed state-space energetic models for four example species (southern elephant seal, North Atlantic right whale, beaked whale, and bottlenose dolphin), that illustrate how specific information about anticipated behavioral changes or reduced resource availability can potentially be used to effectively forecast longer-term, population-level impacts (New et al., 2014; New et al., 2013a; Schick et al., 2013; New et al., 2013b) when enough data are available. However, more work and data are needed before these sorts of models can be broadly applied for management use. In fact, work is still needed even for the more narrow application to specific taxa, as indicated in Pirotta et al. (2014), which illustrates that traditional visual group follow data did not provide enough information to allow biologically robust inference in the case of the model applied to the population-level effects from tourism on bottlenose dolphins in New Zealand (mentioned above).

Unfortunately, empirical data adequate to fully and accurately quantify the relationship between behavioral or physiological changes and fitness impacts do not exist for any marine mammal species, and the existing models for the species with the most data (e.g., elephant seals) are very species- and scenario-specific. However, some inferences regarding the relative importance of certain factors may be appropriate for different species in certain circumstances. Meanwhile, to help address this gap in adequate empirical data, an “interim” version of the PCoD framework has been developed that uses a formal expert elicitation process to estimate parameters (and associated uncertainty) that define how changes in behavior or physiology affect vital rates and incorporate them into a stochastic model. The framework was designed to help predict the anthropogenic disturbances on animal populations in specific circumstances. King et al. (2015) report on the outcome of the first interim PCoD effort to assess the effects of UK offshore wind farm construction on harbor porpoises. Similar efforts are currently underway to evaluate the effects of Navy activities on beaked whales and sperm whales in certain areas and the effects of seismic surveys on Cook Inlet beluga whales. Though care must be taken in the application of predictions based on expert elicitation, the interim PCoD method may appropriately inform impact assessments in certain circumstances. ONR continues to support PCoD work towards species-specific case study energetic models, improved interim expert elicitation processes for data-poor scenarios, and data-based tools that can be more broadly applied to address population-level effects.

Aggregate or Cumulative Effects of Sound

Marine animals, especially in more coastal areas, are often exposed to multiple stressors (including sound) in a given time or space, and there is a general recognition that the cumulative effects of multiple stressors may have a greater impact on individuals or species than a single stressor. In the United States, a variety of federal and state laws require evaluations of cumulative effects in the course of deciding whether and how to authorize or implement a federal or state action. Unfortunately, while guidelines exist for assessing the relative level of cumulative effects on a species, from a practical standpoint this process is quite challenging because of the paucity of data on how various stressors affect species. The effect of a particular stressor on an individual may be dependent on the species, life stage, geographic location, and season, among other variables. Ideally, assessments of cumulative effects would evaluate impacts of the stressor on the population in addition to the individual.

Studies that provide quantitative evidence of population-level effects of one stressor are relatively rare; collecting quantitative information on the population-level effects of all stressors in a system seems virtually unattainable given resource limitations and the complexity of population responses to environmental and human-related features. Given the complexity and the lack of quantitative data on effects of single stressors on marine mammals, regulators often do the best they can to evaluate cumulative effects, at least in a relative fashion, by listing all known activities in a geographic area and making a qualitative assessment of whether the activity is likely to affect the population independently, or in conjunction with other stressors . In one current effort, the National Academies of Science have convened an expert group to conduct a workshop and review the present scientific understanding of cumulative effects of anthropogenic stressors on marine mammals with a focus on anthropogenic sound. The group will further assess current methodologies used for evaluating cumulative effects and identify new approaches that could improve these assessments.

In addition to the challenges with assessing the effects of multiple stressors, it is often challenging to even effectively characterize or predict the likely impacts from multiple sound sources. Several recent efforts have sought to improve our understanding of the aggregate exposure of multiple sound sources on marine mammals. The NOAA-led Cetacean and Sound Mapping Project (http://cetsound.noaa.gov) sought to develop tools to predict and map cumulative, human-induced, annual average low frequency underwater sound fields throughout U.S. managed waters. In 2012, a symposium was held to discuss various methodologies for applying these new maps to managing chronic noise implications for cetacean species, and these maps have been used in first-order chronic noise assessments to inform Environmental Impact Statements. Further integration of noise fields with marine mammal distribution, density and behavioral information to quantify impacts has been addressed in a few place-based case studies. Hatch et al. (2012) sought to quantify levels of masking of biologically important foraging calls made by right whales in and around the Stellwagen Bank National Marine Sanctuary. Streever et al. (2012) modeled the sound fields from various sound sources in the Beaufort Sea, allowed modeled animals to migrate through the area, and calculated an “aggregate exposure” to multiple sources of sound. A follow up effort in the Beaufort Sea is under way that uses expert opinion to assess the likelihood that a response variable will be affected by sound, the severity of the impact if it occurs, and the experts’ certainty that we understand the system sufficiently to make a statement about impacts. Both the quantitative and qualitative approaches could be expanded to include consideration of cumulative effects of stressors other than sound on marine mammals.

CURRENT NOAA MANAGEMENT OF NOISE IMPACTS

NOAA’s responsibilities include the implementation of multiple federal statutes that provide for the protection and conservation of marine species and stocks, as well as their habitat. While the U.S. does not have any federal statutes or regulations in place that are specifically designed to address underwater noise, we currently regulate the impacts of underwater noise (among other impacts, including in air noise) on animal groups for which the agency has responsibility/authority through multiple federal statutes, as well as other initiatives discussed below. It is important to note that, to date, much of the management of noise effects on marine mammals, fish, invertebrates, and sea turtles has occurred through primarily project-specific consultations and permitting pursuant to the MMPA, the ESA, the NMSA, and the MSA. In some instances, other less targeted mechanisms have been used to provide broader recommendations (e.g., Fish and Wildlife Coordination Act to address fish and invertebrate impacts). While some of these consultations are programmatic in nature, their analyses are not typically comprehensive on a scale that would adequately address either the long life spans or very large geographic ranges of all of the marine species potentially impacted, and they don't address aggregate or cumulative effects very well. Additionally, even when the importance of a given area is understood, either for its broader acoustic habitat value or because of known value to a specific species or group, ***places are typically more difficult to manage through the more project-specific lenses of ESA and MMPA*** (though, see Chapter 2)**.**

As a federal agency, pursuant to the National Environmental Policy Act (NEPA), NOAA also has the responsibility to analyze the impacts of its own activities (e.g., conducting scientific research, operating a fleet of vessels, issuing MMPA authorizations) on the human environment. This analysis must consider a range of reasonable alternatives (including mitigation measures), all potentially impacted resources (e.g., biological resources and social resources), and cumulative impacts, and must be made available to both the public and agency decision-makers. The product of this process is a NEPA document that, where appropriate, will include a full discussion of the acoustic impacts of an activity on marine taxa.

NOAA's work with the International Maritime Organization's (IMO) to develop voluntary guidelines for reducing underwater noise from commercial shipping, which were adopted in April 2014 is another important example of NOAA's efforts to more broadly minimize noise impacts on marine species and their acoustic habitats. This international mechanism serves as a long-term tool for NOAA, other U.S. agencies, and other governments to address noise impacts on a broader spatial scale than U.S. statutes allow.

Below we briefly describe the four main statutory authorities through which NOAA currently addresses the impacts of ocean noise on marine species. Appendix C further describes the specific applicable sections of the statutes summarized below and also lists other authorities through which NOAA could address noise impacts on species and acoustic habitat (described further in the "Next Steps for NOAA Ocean Noise Strategy" section.

Marine Mammal Protection Act (MMPA)

The MMPA states that marine mammals are resources of great international significance and should not be permitted to diminish beyond the point at which they cease to be a significant functioning element of the ecosystem. Section 2 (2) of the MMPA further states that the primary objective of their management should be to maintain the health and stability of marine mammals and their ecosystems, and that efforts should be made to protect essential habitats, including rookeries, mating grounds, and areas of similar significance from the adverse effect of man's actions. The MMPA lays out very explicit protections and programs for *all* marine mammal species and stocks and their habitat, and NOAA is responsible for implementing these mandates for most marine mammal species (except for the 5 taxa under USFWS jurisdiction: manatees, dugongs, walrus, polar bears, and sea otters).

As part of the plan to serve this broader goal, the MMPA prohibits the take of marine mammals, with certain exceptions, one of which is the issuance of incidental take authorizations (ITAs). Section 101(a)(5) of the MMPA allows for NOAA/USFWS to issue ITAs provided that: (1) the total taking will have a negligible impact on the affected species (or stock), and (2) the total taking will not have an unmitigable adverse impact on the availability of the affected species or stocks for subsistence uses. Further, NOAA/USFWS must clearly set forth the permissible methods of taking and the requirements pertaining to the mitigation, monitoring and reporting of the take (for more information about Section 101 of the MMPA see http://www.nmfs.noaa.gov/pr/permits/incidental/).

Title IV of the MMPA lays out the responsibilities of NOAA and the USFWS for implementing the Marine Mammal Health and Stranding Response Program (MMHSRP). Pursuant to the MMHSRP, NOAA responds to, investigates, and reports out on marine mammal strandings, including those potentially associated with exposure to loud sounds (for more information about the MMHSRP see http://www.nmfs.noaa.gov/pr/health/stranding.htm).

Endangered Species Act (ESA)

The purposes of the ESA include providing a means to conserve the ecosystems of endangered species and threatened species (those threatened with extinction) and to provide a program for the conservation of the species themselves. The ESA seeks to avoid extinction and recover threatened and endangered species to a point at which they no longer need ESA protections. The Endangered Species Act (ESA) lists the following number of species as threatened or endangered: 27 marine mammals; 57 fish; 16 sea turtles, and; 24 invertebrates.

As one part of a plan to serve these broader goals, Section 9 of the ESA prohibits the take of ESA-listed species, with limited exceptions. Section 7 of the ESA requires that each federal agency, in consultation with NOAA/USFWS, insure that any agency action is not likely to jeopardize the continued existence of any endangered or threatened species, or result in the adverse modification of their critical habitat. Provided these findings are made, incidental take of ESA-listed species may be exempted by NOAA or USFWS. Section 10 of the ESA allows for the issuance of incidental take permits to non-federal entities. NOAA or USFWS typically identify terms and conditions (e.g., mitigation or monitoring) that the action agency or permit holder must abide by in order to be exempted of/permitted for the incidental take.

Section 4 of the ESA allows for the protection of designated critical habitat, which is defined as:

- within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and
- outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation.

Critical habitat is based on ”primary constituent elements,” which are the physical or biological features essential to the conservation of a species, such as space for growth, food, cover, etc. One species of marine mammal, Cook Inlet beluga whale, has a primary constituent element identified in its critical habitat designation that addresses noise impacts: “waters with in-water noise below levels resulting in the abandonment of critical habitat areas by Cook Inlet belugas.” For more information about the Endangered Species Act, visit: http://www.nmfs.noaa.gov/pr/laws/esa/.

National Marine Sanctuaries Act (NMSA)

The NMSA allows for the designation and protection (by NOAA) of national marine sanctuaries -- areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archaeological, educational, or aesthetic qualities. The primary objective is to protect special areas of the marine environment.

Regulations may be issued for specific sanctuaries or the system as a whole, and can (among other things) specify the activities that can and cannot occur within the sanctuary and/or those that require permitting (Section 308). Currently, none of the 14 sites managed or co-managed by the Office of National Marine Sanctuaries (ONMS) prohibit outright the production of underwater noise within their boundaries. However, Section 304(d) of the NMSA additionally requires federal agencies whose actions are likely to destroy, cause the loss of, or injure a sanctuary resource to consult with the ONMS before taking the action. ONMS then recommends reasonable and prudent alternatives (which may include mitigation or monitoring) to protect sanctuary resources. Where noise impacts are addressed, 304(d) recommendations may address any noise-sensitive species within the sanctuary (e.g., marine mammals or fish) as well as targeting acoustic habitat concerns more broadly (for more about management of National Marine Sanctuaries resources see: http://sanctuaries.noaa.gov/management/welcome.html).

Magnuson-Stevens Fishery Conservation and Management Act (MSA)

Fish require healthy surroundings to survive and reproduce. NOAA Fisheries works with regional fishery management councils to identify the essential habitat for every life stage of each federally managed fish and invertebrate species using the best available scientific information. Essential fish habitat (EFH) includes all types of aquatic habitat—wetlands, coral reefs, seagrasses, rivers—where fish (and some invertebrates) spawn, breed, feed, or grow to maturity. Essential fish habitat has been described for approximately 1,000 managed species to date.

NOAA and the councils also identified more than 100 “habitat areas of particular concern” or HAPCs. These are considered high priority areas for conservation, management, or research because they are rare, sensitive, stressed by development, or important to ecosystem function.

Through EFH consultations pursuant to the Magnuson Stevens Act, NOAA works with federal agencies to conserve and enhance essential fish habitat (EFH). Consultation is required when a federal agency authorizes, funds, or undertakes an action that may adversely affect EFH. Adverse effects include: direct or indirect physical, chemical, or biological alterations of the waters or substrate; loss of, or injury to species and their habitat, and other ecosystem components; or reduction of the quality and/or quantity of EFH. The federal agency must provide NOAA Fisheries with an assessment of the action’s impacts to EFH, and NOAA Fisheries provides the federal agency with EFH Conservation Recommendations to avoid, minimize, mitigate, or otherwise offset those adverse effects. Federal agencies must provide a detailed written explanation to NOAA Fisheries describing which recommendations, if any, it has not adopted.

REGULATORY AND ANALYTICAL APPROACHES

The standards, thresholds, and terminology vary, but all of the statutes identified above generally aim to assess and minimize the impacts to individuals, populations, and habitats of marine taxa. Impact analyses conducted pursuant to these different statutes will sometimes use different analytical methods because of the differences in the requirements of the statutes or the nature of the activities or impacts assessed, but they are all required to be based upon the best available science.

Acoustic Thresholds

One tool that NOAA currently uses to characterize and assess acute impacts of noise exposure is acoustic exposure thresholds. For marine mammals, these generic thresholds have historically (for the most part) been presented in the form of single received levels for particular source categories (e.g., impulse or continuous,) above which an exposed animal would be predicted to incur auditory injury or be behaviorally harassed. For example, root mean square (RMS) sound pressure level (SPL) 180 and 190 dB thresholds have been used for the onset of ***acoustic injury*** of cetaceans and pinnipeds, respectively, and RMS SPL 160 and 120 dB thresholds have been used for the onset of ***behavioral harassment*** of all marine mammals from impulse and continuous sources, respectively. These two specific effect types (acoustic injury and behavioral harassment) align well with statutory definitions of some components of “take” in MMPA and ESA, and “injury” under the NMSA. NOAA has also used dose-response-type curves to quantify behavioral harassment of marine mammals from active sonar involved in military readiness activities.

Because of the paucity of information for fishes, sea turtles, and invertebrates, acoustic thresholds have been applied in a more regionally-specific manner, and often only specifically in the context of particular activity types for which adverse effects have been documented (e.g., sea turtles to explosives). Generally, more supporting data exist for frequently conducted activities that produce acute, intense, high energy, impulsive sounds, such as pile driving, underwater explosions, and seismic surveys. For example, a coalition of federal (including NOAA Fisheries West Coast Region) and state resources and transportation agencies along the West Coast, the Fisheries Hydroacoustic Working Group (FHWG), used data from a variety of sound sources (primarily underwater explosions and seismic airguns) and species to establish interim acoustic criteria for the onset of injury of fish from impact pile driving (FHWG 2008). These criteria, in turn, are sometimes used to estimate the risk to fishes from other types of impulsive sounds. They are not appropriate, however, for non-impulsive, continuous sounds. However, several impact pile driving and other sound source studies have been conducted since the 2008 thresholds were established, and may be used in the future to revisit these criteria and develop different ones for fishes specifically for pile driving and other impulsive and non-impulsive sound sources (e.g., Casper et al. 2012, Casper et al. 2013, Bolle et al. 2012, Halvorsen et al. 2011, Halvorsen et al. 2012a,b,c, Halvorsen et al. 2013, Hawkins et al. 2014a, Bolle et al. 2016). Most historical research has used peak pressure to evaluate the effects on fishes from underwater sound. Current research, however, suggests that sound exposure level (SEL_{cum}), a measure of the total sound energy expressed as the time-integrated, sound pressure squared, is also a relevant metric for evaluating the effects of sound on fish.

It is important to note that the identification of these likely direct physical or behavioral effects via the use of acoustic thresholds is only one part of any broader impact finding under MMPA, ESA, MSA or NMSA, and does not consider adverse stress effects. These statutes must also assess impacts on habitat (including acoustic habitat), as well as the ultimate results of all of the effects on the fitness of individuals (health, reproductive success, and survival) and subsequent population growth rates and/or likely impacts to resources within sanctuaries. However, acoustic thresholds are important both because they help regulated entities understand when a federal consultation may be appropriate and because of requirements under both the MMPA and ESA to quantify the impacts of acoustic exposure on a project-by-project basis.

One of the limitations of relying on the action-specific regulatory approaches of the MMPA, ESA, MSA and NMSA to address the impacts of noise is that it makes it more challenging to address chronic (longer-term) and multi-source impacts that co-occur across longer time frames, larger areas, and multiple activities. Additionally, some activities that contribute significantly to background noise levels are challenging, if not impossible, to regulate case-specifically (e.g., large commercial shipping) or do not typically go through the MMPA, ESA, MSA, or NMSA processes. To date, acoustic habitat has not been regularly addressed in MMPA, ESA, MSA, or NMSA consultations.

Mitigation

The activity-specific structure of the current regulatory framework also means that there is not a standard required set of mitigation or monitoring to always apply to noise-producing activities. That said, the following types of mitigation measures are commonly required or recommended to address acoustic impacts to marine mammals, and a subset of them are sometimes applied to other taxa, though protective measures for fish, invertebrates, and sea turtles are typically more limited to mitigating the potential for acute injurious impacts:

- Real-time detection and action (to limit acute/direct impacts)
    - Power down/shutdown zones to minimize the likelihood of injury to marine mammals, fish, turtles or invertebrates, or the behavioral harassment of large groups of marine mammals or mother/calf or pup pairs
    - Visual observers for protected species (shore, ship and aerial, unmanned crafts) and/or passive acoustic technicians (increasingly common) to support real-time measures
    - Daytime operations only or use of nighttime specific technology to enhance detection
- Seasonal/Area Limitations (to limit chronic/long-term effects, but also acute effects including behavioral)
    - Avoidance/minimization of operations in seasons and/or areas of biological importance or with particularly sensitive species(e.g., sanctuaries, HAPCs, salmon migration routes, critical habitat)
- Noise abatement/reduction (to reduce both chronic and acute impacts)
    - Sound attenuation methods for pile driving (bubble curtains, pile caps, etc.)
    - Ramp-up procedures with airguns (and sometimes pile driving)
- Sound source verification to ensure adequate mitigation zones and accurate prediction of effects

Of note, protected species observers (PSOs) are used for many activities with the potential to adversely impact marine fauna, both to implement mitigation measures, such as shutdowns or to ensure that safety zones are clear before activities take place, and to collect data for monitoring. NOAA published the NOAA Technical Memorandum “National Standards for a Protected Species Observer and Data Management Program” (Baker et al, 2014), which provides recommendations to more broadly enhance coordination, establish national PSO standards for qualifications and training, institute standardized data collection and reporting requirements, and develop data quality assurance process, among other things that could be used to support a more consistent approach.

Monitoring

As noted above, the MMPA has an explicit requirement for monitoring to better understand the impact of authorized activities on marine mammals, and the ESA, NMSA, and EFH also contain mechanisms for including monitoring requirements (note the requirements discussed in this section are separate from NOAA’s separate internal mandate to conduct science). Because the activities requiring permits and consultations range so widely in temporal and spatial scope, monitoring plans that satisfy the requirements also range in robustness and scope. For example, monitoring requirements may range from pinniped counts conducted before, during, and after a small pier maintenance action to full-fledged (and sometimes peer-reviewed) research projects for oil and gas development or Navy training (see http://www.navymarinespeciesmonitoring.us/regions/ for full details of all required monitoring study objectives, methods, timelines, funding, and completed results). Reports containing monitoring results must be submitted and NOAA subsequently makes those reports available to the public. Transparency and sharing of *raw* data has increased through time and may now largely be obtained, if requested, with the exception of acoustic data that may implicate national security concerns (acoustic signal or locational data) or proprietary energy lease information (locational data).

NEXT STEPS FOR THE NOAA OCEAN NOISE STRATEGY

The purpose of NOAA's Ocean Noise Strategy, as highlighted here in this Roadmap, is to focus the agency's authority and capacity to characterize and manage ocean noise impacts for the benefit of NOAA trust resources. Through expertise and authority, the goal is for individual NOAA programs (regulatory, science, and noise-producing) to identify recommendations and concepts in this Roadmap that are most applicable and constructive towards their broader program goals, and work them into a program-specific implementation plan. Management strategies, risk assessment tool needs, and monitoring and science needs will necessarily vary among species, populations, and habitat. However, some science and advancements in management approaches may also be relevant across species groups and areas, providing opportunity for collaboration and consolidation of agency resources. Eight broadly applicable, high priority areas of agency improvement are identified here (in no particular order):

1. Consistent Messaging, Internal Education, and Coordination: All NOAA offices should, ideally, be using the same terminology and concepts to describe the issues surrounding aquatic noise impacts on species and acoustic habitat. The development and compilation of a glossary of noise terms and concepts, especially as they relate to effects on marine species and their acoustic habitats, would be very helpful and could be developed by expanding the glossary developed for NOAA's new acoustic guidelines. Beyond a common lexicon, NOAA should be consistently describing the full suite and relative importance of the potential effects of noise in both internal and external settings. This Roadmap aims in particular to support the agency's consistent articulation of the importance of protecting acoustic habitat, in addition to minimizing acute (physical and behavioral), chronic, and cumulative impacts associated with noise. Additional work would be needed to develop the glossary and ensure that NOAA's workforce is well-versed in the basics of acoustics (introductory materials to more advanced materials), as well as the latest science on the impacts of noise on marine species and habitats.

NOAA programs with a noise impact nexus are implemented across the agency through multiple line offices and levels (national, regional, specific sanctuaries, etc.). Clearly, it is critical that coordination is planned across these programs where appropriate. For example, it makes sense, both biologically and logistically, to regularly coordinate mitigation and monitoring priorities, as well as any new risk assessment methodologies or science, across the primary regulatory programs. One ongoing example of successful internal coordination and information sharing is the NOAA Acoustic Coordination Group, which meets 3-4 times a year, and sponsors a listserv to discuss both management and science issues related to acoustics.

2. National Guidance for Acoustic Thresholds and Other Management Tools: The development of consistent national guidance for acoustic thresholds for all of NOAA's trust resources would provide strong support for NOAA's accomplishment of the Strategy goals. In a process separate from this Roadmap, NOAA has developed the "Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing" that includes revised acoustic thresholds for assessing acoustic impacts on marine mammal hearing (permanent and temporary threshold shifts) (NMFS 2016). The Guidance's review process included multiple peer and public reviews of the scientific rationale and methods. NOAA is now working on developing updated Technical Guidance to assess behavioral harassment of marine mammals. To support the Strategy goals, NOAA could pursue developing similar national acoustic injury thresholds for fish, sea turtles, and, potentially invertebrates. While official national guidance on acoustic thresholds is being developed for any of these purposes, coordinated interim principles and practices would ensure consistent application of existing acoustic data.

For NOAA management practitioners, it is valuable to have guidelines that describe how to implement various typical management recommendations that can be shared with the regulated community. Examples of these types of guidance include how to do sound source verification, how to estimate isopleths associated with different effect thresholds, or how to design effective passive acoustic monitoring (PAM) for a particular project. These types of guidelines could be developed and implemented nationally (with regional and program input) to promote consistency and alleviate either duplicative effort or contradicting recommendations across regions and programs.

3. Exploring and Coordinating the Use of Applicable NOAA Authorities: In the previous section, the federal statutes through which NOAA has traditionally addressed ocean noise impacts were outlined. Appendix C contains a spreadsheet indicating a longer list of the applicable statutes, executive orders, and other formal programs (and specific mechanisms and Sections) through which NOAA *could* address ocean noise issues, both in relation to specific species *and also* acoustic habitat, either through raising awareness, making official recommendations, or including regulatory requirements. We recommend that the NOAA Programs implementing these statutes work together to add reference to ocean noise issues (using the consistent messaging mentioned above) where not currently addressed. Additionally, improved coordination between, for example, regulatory MMPA and ESA programs and the Marine Mammal Health and Stranding Response Program, such as overlaying maps of authorized sound use activities with unusual mortality events, spill or stranding investigations, or other health indicators (along with the subsequent analyses triggered by the mapping connections), could facilitate better assessment and prediction of the impacts of noise on individuals and/or populations .

Traditional approaches to regulating ocean noise issues have necessarily been somewhat constrained by the project-specific and shorter-term focus of the statues under which NOAA worked. However, there is some temporal and spatial flexibility in the traditionally-used statues to explore broader (e.g., programmatic) approaches to analysis and management of chronic large-scale impacts. Additionally, consideration of some of the additional tools presented in Appendix C gives NOAA more room to coordinate broader-scale strategies across multiple programs, as resources and opportunities allow – provided we have a well-articulated justification and approach. Additionally, Chapter 2 outlines a broad place-based approach for prioritizing the management of acoustic habitat.

Last, when considering approaches for addressing ocean noise impacts, international examples are available. The European Union has recognized ocean noise as an indicator of environmental quality under its Marine Strategy Framework Directive (EU 2008) and, further, is in the process of developing targets for achieving “good environmental status” for ocean noise and acute noise-generating activities. Nowacek et al., 2015, identify existing international mechanisms that they suggest could potentially be modified to address ocean noise impacts, such as the International Convention for the Prevention of Pollution from Ships.

4. Development of Risk Assessment Tools: To support the Strategy, risk assessment tools would be targeted towards the analyses required to support decisions under NOAA’s statutory authorities, which essentially involve characterizing, analyzing, and mitigating the impacts of sound on individuals, stocks, populations (see Chapter 4), and their habitat (including acoustic habitat).

Spatially explicit risk assessments are an important tool for developing and prioritizing management actions. Specific targets could include maintaining lower background noise levels in acoustic habitat or reducing noise in areas of high densities of acoustically sensitive species. We can quantify risk by combining species distributions, species-specific acoustic sensitivities, and sound maps. Risk assessments may be conducted comparing the highest intensity of sound received from specific activities (e.g., navy sonar, seismic airguns, or pile driving) or comparing highest energy accumulated over time from chronic and aggregated sound sources (e.g., shipping lanes), depending on whether risk from acute or chronic noise is being assessed. These assessments can be used to identify the most effective management actions at reducing impacts by evaluating changes in predicted impacts when changes in sound-producing activities and sound levels are applied. This type of assessment focuses on impacts in defined geographic areas. Alternatively, it may be important to consider cumulative noise impacts faced by individuals throughout their lifetime. This type of assessment requires integrating risk across all areas used by the individuals (e.g., breeding and feeding areas *and* migratory corridors). Having the tools available to conduct both types of assessment, along with others, will strengthen and support NOAA's conservation actions and related decisions, and further aid the public and regulated community in planning and analyses to support environmental compliance and impact minimization.

Following are some of the basic components that would allow the sorts of risk assessments outlined above and to create a more effective NOAA risk assessment framework:

- Tools to model: (1) sound propagation in the context of realistic environmental parameters, and; (2) marine animal sound exposure. Output would be available in a variety of metrics and be capable of addressing accumulation over time and auditory weighting functions.
- Data to inform, or tools to model, ambient or average background sound levels (soundscape, see Chapter 3) over which risk assessments may be layered (including a database of measured sound source verifications).
- Maps of NOAA-authorized activities (produced by NOAA) and noise-producing activities not regulated by NOAA, where available (e.g., Marine Cadastre website).
- Platforms, servers, and data layers that allow for the geospatial analysis of the temporally, spatially, and spectrally-specific overlays of sound-producing activities and protected marine species at a wide range of temporal and spatial scales.
- Permanently maintained, standardized, and web-accessible database or portal for acoustic and marine animal data.

These tools are a high priority for NOAA practitioners, but would also ideally be made available to the public as soon as possible.

Further development of risk assessment frameworks will require improved quantitative capacity to evaluate the population-level and cumulative consequences resulting from co-occurrence of noise and marine animals. These frameworks and models would include consideration of health and disease risks where known and be applicable to certain species. In addition to the PCoD effort mentioned previously and other marine mammal-centric efforts underway, there are numerous well-developed risk assessment frameworks in the toxicology field that could potentially applied to noise and aquatic animal issues.

Specifically in regard to the better understanding of chronic noise effects, new quantitative tools are currently being developed that may be able to better characterize the acoustic space available to an animal to detect critical acoustic cues. The information is gained from our understanding of the animal's hearing, vocal behavior, and the surrounding soundscape, which is informed by both natural and anthropogenic sounds (Clark et al. 2009). However, these highly specific and quantitative tools can be resource-prohibitive for project-specific analyses. In addition, managers still struggle to connect the quantification of reduced acoustic space with a particular degree of impacts on protected species, either at the individual or population level. There is a need for the development of semi-quantitative tools, either standing alone or built into broader analyses, in which masking or acoustic habitat degradation effects can be incorporated for consideration.

In the past, noise impact assessments have relied heavily on the received sound level of which an animal was likely to be exposed in order to estimate the likely severity of the resulting impacts. However, in addition to targeted studies in marine mammals and fish indicating that frequency and duration (beyond just differing sensitivities at different frequencies) can affect the likelihood of auditory impairment, there is increasing evidence that contextual factors other than the received sound level are important in assessing impacts. Contextual factors including the activity states of exposed animals, the novelty of a sound, and the relative spatial positions between sound source and receiver, can strongly affect the probability of a behavioral response and the significance of that response to the fitness of the exposed individual (Ellison et al. 2011). For an accurate characterization and evaluation of likely noise impacts, it is critical to consider not only frequency and other sound characteristics, but other contextual factors when the information is available (Francis and Barber 2013).

5. Prioritize Baseline Science Needs: The highest priority science needs for assessing and minimizing acoustic impacts can be arranged along a continuum from understanding individual components of the problem (mapping sound and species distributions and quantifying the effects of sound on individuals and populations) to synthesizing information in risk assessments. A list of *general* priority information needs (non-comprehensive and in no particular order) for noise assessment appears below. These can be more specifically focused by taxa or species based on the status of existing data summarized in Appendices A and B, though generally speaking, more basic information is needed for sea turtles, invertebrates, and fish. Chapter 3 also addresses key information gaps in NOAA's current understanding of soundscapes and a need for enhanced passive acoustic monitoring. NOAA has already begun collecting, compiling and making available some of this information.

- Presence, abundance, density, and distribution mapping of protected species and prey, including:
    - prioritization based on overall vulnerability and noise sensitivity, as well as ecosystem assessments
    - for existing datasets - increased spatial and temporal resolution
    - systematic updates
- Increased understanding of species sound use, auditory thresholds and hearing mechanisms, especially for non-marine mammal species, including:
    - differentiation of life stages for fishes
    - special emphasis on turtles
- Increased understanding of noise levels that cause hearing loss, other physical injuries and masking especially for fishes, but also for invertebrates, turtles, and mysticetes including:
    - prioritization of science based on sound sources known to pose more risk to species
    - increased understanding of other environmental factors that contribute to hearing loss and other impacts.
    - Increased understanding of particle motion effects
- Increased understanding of behavioral sensitivity and responses to noise, including:
    - for marine mammals, responses to actual sound sources under realistic exposure conditions and duration (e.g., caution with laboratory studies)

  - baseline behavioral data to compare noise-induced changes to
  - targeted attention to effects of contextual variables beyond sound level
  - targeted attention to effects at multiple scales (e.g., tags that track horizontal movement *and* tags that record finer scale data such as clicks, acceleration, dive tracks)
- Identification of times, areas or species of particular concern for risk assessment, e.g.:
  - important areas for reproduction, feeding, migration, etc.
  - particular contextual situations of concern (e.g., populations undergoing severe epidemic or heavy exposure to oil spill)
  - identification of fish and invertebrate species that may be particularly susceptible to human noise (based on functional hearing or broad responses to sound) prioritized according to species that are ecologically, commercially and recreationally important.
- Collection of baseline stress-marker datasets to which field measurements can be compared to appropriately to assess context and significance of noise-caused adverse stress responses.
- Increased understanding of masking (see Chapters 2 and 3) and, importantly, the consequences of reduced listening space for all taxa.
- Soundscape characterization and mapping (see Chapter 3), including:
  - long-term monitoring of background noise in frequency bands relative to marine species hearing
  - location, timing, intensity and frequency of particular sound sources
- Collection and understanding of basic energetic information to link individual responses to effects on survivorship and reproductive success and, ultimately, population-level consequences.
- Understanding of effects of aggregate noise sources, as well as cumulative effects of noise with non-acoustic sources

Of note, NOAA has developed an internal process for compiling key science needs (more broadly) at the regional level. Maintenance of key science needs for assessing acoustic impacts should be cross-referenced with the regional Protected Resources Science Investment and Planning Process (PRSIPP) to ensure inclusion of newest science from the Science Centers, as well as to inform the broader NOAA science prioritization process.

6. Continue to Support Mitigation Development: Where noise is concerned, mitigation should be broadly designed to do one of two things: (1) reduce the temporal or spatial overlap of ensonified areas with marine taxa (or acoustic habitat) in particular times, places or circumstances, and/or (2) reduce the sound level at the source (which may include replacing the source with a different type of source capable of the same function). In reducing the spatio-temporal overlay of noise with marine animals and acoustic habitat, there are two general types of solutions: real-time avoidance of overlap of sound and managed species, and pre-planned larger-scale avoidance of sound use in important areas or times. Real-time measures are typically used to minimize acute effects, such as injury or severe behavioral responses, whereas broader activity planning may reduce acute, and potentially significant, behavioral effects, and is also the most effective spatiotemporal method to address more chronic acoustic habitat effects, such as masking.

In addition to improving and expanding some of the traditional mitigation measures identified in the previous section (e.g., real-time shutdowns and project-specific sound attenuation), and referring to the bulleted lists immediately above, it is important to continue engaging stakeholders and focusing on broader-scale technological development that will result in noise reduction over multiple projects and long time-scales. These include continued vessel quieting improvements and the exploration of technologies that can replace louder or more impactful sound sources (e.g., seismic airguns) with quieter sources that provide the same functionality while introducing less sound into the water. Additionally, we need to continue to identify the areas/times/contexts that are most critical to marine species so that we can reduce their overlay with potentially harmful sound exposure. Also, we need to continue to develop technologies and methodologies to enhance the detection of marine species (e.g., infrared, glider platforms). Finally, we need to incorporate communication protocols that facilitate rapid response when serious injury or stranding occurs concurrently with authorized or permitted sound-producing activities.

7. Enhance Efficacy and Transparency of Monitoring Approaches: As noted above, the MMPA has an explicit requirement for monitoring to better understand what impact the authorized activities have on marine mammals. The ESA, NMSA, and EFH also contain mechanisms for including monitoring requirements for assessing or quantifying the effects of managed activities on marine mammals, sea turtles, fishes, invertebrates, and their habitat. In other words, through its regulatory mandates, NOAA has the authority to require monitoring from entities seeking authorization to impact NOAA trust resources pursuant to the statutes described earlier in this Chapter, and for assessing the impacts of physical environmental parameters on marine mammal health (MMPA Title IV). This required monitoring should typically be commensurate with the anticipated impacts, and NOAA has gathered significant amounts of valuable information through these requirements in the past.

When NOAA program analysts consider recommended monitoring for activities with acoustic impacts, focusing on the concepts below would allow NOAA to ensure the best use of resources both within the Agency and by the entities/agencies from which NOAA requires monitoring:

- Keep in mind the priority data gaps identified above in the Science Needs section, and further maintain a list of specific priority study questions that relate to the applicable region and regulatory authority through which the analysts are recommending/requiring monitoring.
- Both in recommending monitoring and in maintaining a list of priority questions that monitoring should be designed to address, keep the following in mind:
    - The variety of timescales, asset/resource availability, and complexity across which monitoring may be applied (e.g., a daily pinniped beach census versus a controlled behavioral response study utilizing tags and multiple platforms)
    - The potential for meta-analyses of multiple monitoring efforts contributing to bigger questions
    - The need for methods standardization (e.g., addressing potential biases, requiring methods and reporting formats that allow for the most effective interpretation of results, as well as comparison to, and integration with, other results)
- Ensure that monitoring requirements and list of priority questions are informed by:
    - Evolving science and previous monitoring results
    - An understanding of regional ecosystem function
    - Existing and ongoing studies and programs to leverage monitoring
- Develop mechanism(s) to detect how multiple activities might contribute to a combined effect on individuals or a population.
- Incorporate adaptive components that will allow for modification of measures or solicitation of additional information as needs emerge through the regulatory timeframe.
- Ensure adequate data storage, sharing, and accessibility to NOAA users and the public
- Develop and implement a transparent process to:

  - Educate and focus the regulated community on priority questions
  - Integrate incoming monitoring data between applicants, as well as among scientists
  - Regularly review and adapt priority questions

NOAA has worked extensively with the Navy over about 10 years on the development of their Comprehensive Monitoring Plan, through which they address the monitoring requirements of the MMPA and ESA for Navy training and testing activities across multiple regions within the US EEZ. Their monitoring provides a good example of an integrated, goal-oriented, and transparent monitoring process (see http://www.navymarinespeciesmonitoring.us/regions/). Similarly, BP engaged a scientific advisory group and worked extensively over years with resource agencies and subsistence communities to implement a long-term monitoring plan that addressed the impacts of the operation of the Northstar production island and led to multiple peer-reviewed articles that inform impact analyses today. Other companies in the Arctic, such as Shell and Conoco Phillips, have also supported good collaboration and robust monitoring plans that have improved our understanding of the effects of seismic operations (see NMFS project website for monitoring reports from : http://www.nmfs.noaa.gov/pr/permits/incidental/oilgas.htm).

8. Develop Mechanisms for Outreach, Collaboration, and Stakeholder Engagement: To fully support the Strategy, NOAA would promote public understanding of noise impacts in U.S. waters and abroad through targeted outreach efforts. There are multiple reasons why engagement with stakeholders is critical. Much of the research related to noise effects is conducted by entities outside of NOAA, including other Federal agencies (e.g., Navy or BOEM) and academic institutions or consortiums. Also, engagement with the regulated, or noise-producing, community allows NOAA to ensure that noise management implementation plans are effective and practicable. Systematic and regular engagement with stakeholders allows for coordination of related research, management, and risk assessment efforts to maximize synergy and resource savings. Over the course of NOAA's CetSound and NOAA Ocean Noise Strategy efforts, NOAA, Navy, BOEM, the Marine Mammal Commission, Duke University, Heat, Light, and Sound Inc., and others have collaborated and jointly funded (multiple separate examples and partners) marine mammal surveys, marine mammal density modeling, soundscape modeling, the development of risk assessment tools, expert elicitation to identify biologically important areas, and multiple workshops to address specific noise-related issues – all of which advance our collective ability to more effectively address the effects of noise on protected species and their habitat. NOAA will continue to explore and invite input regarding mechanisms to improve collaboration, including joint development and funding of workshops and decision-making tools, inter-disciplinary and inter-agency working groups, targeted solicitation of input through regulatory processes, and other methods.

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Can You Hear Me Here? Managing Acoustic Habitat in U.S. Waters[6]

INTRODUCTION

The U.S. National Oceanic and Atmospheric Administration (NOAA) is a steward of the nation's oceans, with a variety of statutory mandates for conservation and management of coastal and marine ecosystems and resources of ecological, economic, and cultural significance. To this end, NOAA is charged with protecting the long-term health of a wide variety of aquatic animal populations and the habitats that support them, including whales, dolphins, sea turtles, fishes, and invertebrates. While these animals fill very different roles in marine ecosystems, many of them share a common and fundamental biological need: the ability to hear, produce, and respond to sound.

The purposeful use of sound for communication by marine mammals, many fish, and a few marine invertebrates is well documented (reviewed by Tyack & Clark 2000, Normandeau Associates 2012, Ladich 2015). For example, fin and blue whales produce low frequency calls that are thought to play roles in finding mates, sharing food resource information, and navigating at ocean basin scales (Payne & Webb 1971, Morano et al., 2012). In contrast, bottlenose dolphins use higher frequency signals to maintain social structure, identify individuals, and echolocate during foraging (Janik & Slater 1998). Some fish species are well known to produce loud low frequency choruses for communicating with conspecifics and attracting mates (Myrberg 1981). Cavitating bubbles produced by snapping shrimp emit sound upon their collapse that stun prey and provide a means for individuals to communicate with one another and defend territories (Versluis et al., 2000). In addition, there is evidence from both terrestrial and marine organisms illustrating the ecological importance of adventitious sounds: those gathered opportunistically from the surrounding habitat through eavesdropping rather than from a purposeful sender (Barber et al., 2010, Slabbekoorn et al., 2010, Radford et al., 2014).

Many animals hear and respond to frequencies outside of those they produce, underscoring the importance of eavesdropping on other species or of detecting meaningful sounds made by the physical environment. Aquatic examples are wide ranging, including baleen whales responding to sounds within frequencies used by killer whales (e.g., Goldbogen et al., 2013), herring detecting sounds used by echo-locating whales, fish and crab larvae using reef sounds dominated by snapping shrimp as directional cues, sharks approaching the sounds made by struggling prey and surface-feeding fish responding to sounds of prey falling into the water (reviewed by Slabbekoorn et al., 2010, p. 183). Barber et al. (2010) summarize a pattern that appears broadly consistent for both terrestrial and marine realms: "*It is clear that the acoustical environment is not a collection of private conversations between signaler and receiver but an interconnected landscape of information networks*". As defined for humans by the International Standards Organization (2014), soundscapes are a "perceptual construct" inclusive of all the sounds *perceived* by people in a place. Wildlife ecologists, however, more typically characterize soundscapes as all the sounds *present* in a particular location and time (Pijanowski et al., 2011). The complex and dynamic assemblages of natural sounds that contribute to soundscapes are inherent aspects of discrete marine habitats inhabited by individual species and ecological communities (Figure 2-1). Thus, as experienced by the animals inhabiting it, a soundscape may also be referred to as "acoustic habitat" (Clark et al., 2009, Moore et al., 2012a, Merchant et al., 2015).

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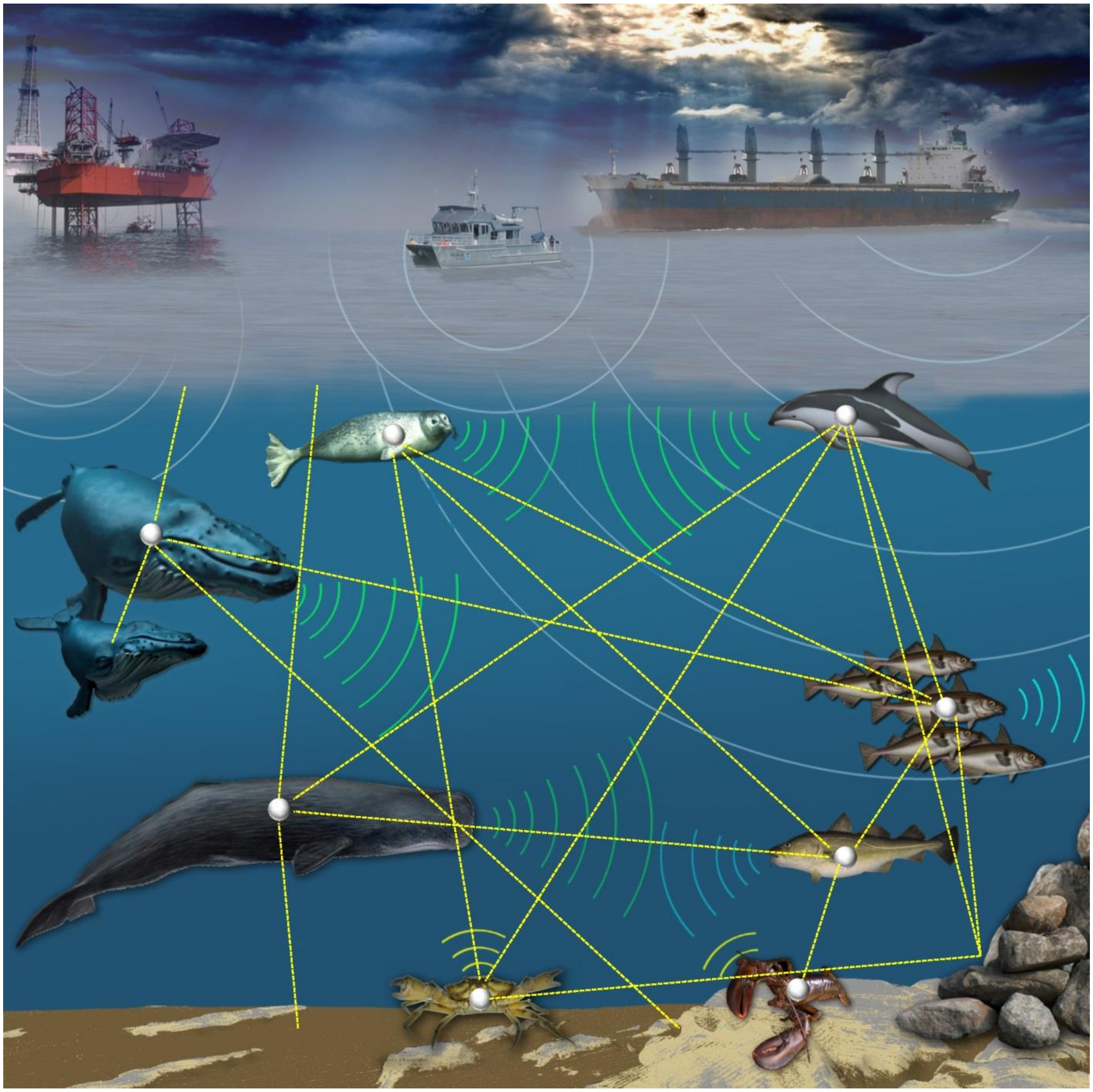


Figure 2-1. Potential acoustically mediated information pathways (yellow dotted lines) in a marine community, including, but not limited to, purposeful communication between individuals, use of echolocation over distances (large and small), eavesdropping on sounds made by other animals, detection of human activities, and identification of seafloor characteristics, all supporting biologically important behaviors such as settlement, recruitment, feeding, migration, and reproduction. White circles and blue, green and yellow semicircles generically represent information-gathering opportunities and sound production, respectively.

Acoustic habitats identified today are often significantly modified by noise produced by human activities, and thus efforts must be made to characterize both their natural and altered conditions. Such activities, and the resulting noise levels that they produce, are increasing throughout coastal and ocean waters in both time and distribution. There are few aquatic areas where anthropogenic noise is absent. Changes in noise conditions over time are predicted to vary considerably among ocean and coastal areas. In some heavily used areas, several-fold increases in the contribution of human noise to acoustic habitats have been measured over just a few decades (Andrews et al., 2002, McDonald et al., 2006). While some marine animals are capable of adjusting communication signals in the presence of noise (e.g., Holt et al., 2009, Parks et al., 2010), it is unknown whether these changes can transfer between generations or whether they result in long-term fitness consequences (see Francis and Barber, 2013 for discussion of evolutionary traps and maladaptive consequences of signal modification in the presence of noise). As reviewed by Erbe et al. (2016), animals have evolved some mechanisms to improve their ability to perceive signals of biological importance in the presence of some noise. However, relative to the life spans of marine organisms, noise levels in many coastal and offshore areas have seen significant growth over just a handful (e.g., some fish, turtles and marine mammals) to tens (e.g., some fish and invertebrates) of generations. Given this rapid increase, the potential for evolved mechanisms to ameliorate loss of acoustic information in many contemporary noise environments is likely to be limited. Additionally, Barber et al. (2010) remind us that while evolutionary adaptation to reduce masking of communication signals can act on both conspecific senders and receivers, mechanisms to improve perception of a wide variety of incidental sounds relative to a wide variety of noise types must be far less singularly focused (resulting in less selective pressure) and are limited to the listeners.

NOAA recognizes the need to develop an approach to underwater noise management that considers not only its effects on individual animals, but also the importance of natural sounds in the places where those animals live. As the world’s coasts and oceans become busier and noisier, NOAA will be challenged to craft and implement new management approaches that balance the competing needs of coastal and ocean resource users and natural acoustic habitats. In this paper, we describe key elements of an agency-wide strategy to more comprehensively manage noise impacts to acoustic habitats, including implications for the science needed to assess habitat status and noise influences. We then examine NOAA’s management tools and consider their application to acoustic habitat protection goals, highlighting activities that are underway or could be undertaken to achieve these goals.

BROADENING NOAA’S NOISE MANAGEMENT APPROACH

Describing Acoustic Habitats

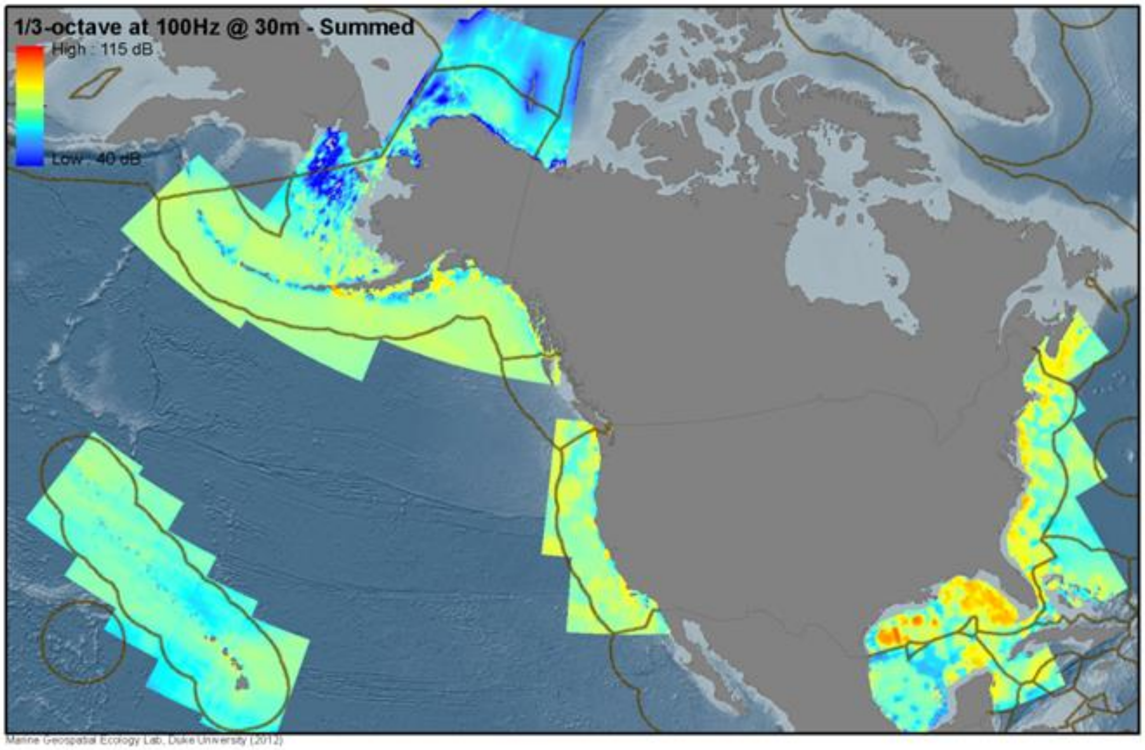
The place where an animal lives is called its “habitat” and is described by its physical and biological attributes, including its acoustic conditions. Under strict habitat definitions, acoustic habitat is an attribute of the area surrounding individual animals; however, the concept is commonly expanded to refer to habitat as the place where multiple species occur together under similar environmental conditions. A habitat can therefore be distinguished from surrounding habitats on the basis of both its species composition and its physical environmental characteristics (e.g., type of seabed, tidal currents, salinity). An acoustic habitat can similarly be attributed to an assemblage of species that are known to collectively experience and often contribute to a natural soundscape that is distinguishable from surrounding soundscapes. Soundscape measurements can be associated with aquatic habitats that have been classified using more traditional data types (e.g., McWilliams & Hawkins 2013, Lillis et al., 2014). Such measurements can illustrate variance in space, time, and frequency content, depending on what species are present at the time of measurement. For example, natural acoustic habitats within tropical reef areas may be heavily dominated by the popping of snapping shrimp and will therefore differ dramatically from those within temperate boulder fields inhabited by the grunting and thrumming of fish such as cusk, sculpin and cod (e.g., Rountree et al., 2006, Staaterman et al., 2013). Acoustic habitats may vary seasonally in association with the presence of animals that produce sounds, whether they are feeding, reproducing, or simply migrating through the area (e.g., Moore et al., 2012b, Parks et al., 2014). Environmental sources of sound can also show strong temporal trends, such as louder, stormier winter months and quieter, lower wind summer months, contributing to large intra-annual differences in natural acoustic habitats (Wenz 1962, Urick 1983). Such natural sources of variance must be accounted for in further evaluating alterations of such habitats by noise from human activities.

Although a few noise sources produce relatively consistent acoustic input to habitats (e.g., large commercial shipping) the cumulative footprint of noise from human activities is often dynamic. Noise made by human activities varies widely in its frequency content, duration and loudness. Consequently, anthropogenic noise can affect acoustic habitats locally for brief periods of time as well as chronically over large areas for long durations. The characteristics of noise sources greatly influence the types of impacts they may have on marine animals and their acoustic habitats. At close proximity, loud noises can result in hearing damage and other physical injury to, or even death of, animals. Sudden, erratic or acute noises can additionally be perceived as threats, leading to adverse responses, while frequent and chronic noise can interrupt communication and disrupt the ability to detect acoustic cues. All of these types of impacts can have viability consequences (see Figure 3, Francis & Barber 2013).

Studies of fishes have quantified the negative impacts of noise-disrupted behavioral patterns on foraging success (Purser & Radford 2011) and predator awareness (Voellmy et al., 2014, Simpson et al., 2015). Effects of lost listening opportunities in noisy conditions can be assessed for specific, identified environmental or adventitious cues of importance, or more generally based on reduction in the volume of space available for acoustic detection (see Box 2, Barber et al., 2010). Time-series data documenting changes in noise conditions are not typically available. Estimates of change in the status of acoustic habitats can incorporate contemporary noise measurements and predictive modeling with and without noise sources, or historical measurements made in areas with similar oceanographic parameters (e.g., Hatch et al., 2012). More recently, the U.S. National Park Service has been developing modeling techniques to predict levels of noise under different conditions for large areas of the continental U.S.A., with one purpose being to gauge progress towards park soundscape management goals (Mennitt et al., 2014).

NOAA's Tools for Acoustic Habitat Risk Assessment

The need to develop long-term recording assets in U.S. waters to enable full characterization of localized acoustic habitats, and support standardized comparisons both within habitats over time and among habitats of potential management interest, is well recognized both by NOAA and other federal agencies (Southall et al., 2009). Some places, such as Stellwagen Bank National Marine Sanctuary and the northeast region in general, have developed longer-term and higher-resolution monitoring efforts as a result of established collaborations between NOAA scientists and non-federal partners, relying on substantial funding from other federal agencies (Van Parijs et al., 2015b). Longer-term recordings have also been funded by non-NOAA federal agencies associated with monitoring the impacts of established noise-producing activities in acoustic habitats of interest to NOAA (e.g., off Southern California and North Carolina associated with military training ranges and in the Alaskan Arctic associated with oil and gas exploration and extraction). NOAA is working with these partners to ensure that such data assets can support assessments of both baseline conditions of acoustic habitats and changes in their status through time. Despite efforts to improve and increase standardized passive acoustic data collection, NOAA cannot listen to all the places in its management charge all the time. Sound-field modeling provides opportunities to characterize acoustic habitat conditions in places with no or limited measurements, and to explore the predicted consequences associated with changes in the types, distributions and densities of noise-producing activities over time. NOAA has invested in the development of such modeling approaches within U.S. waters at various resolutions and scales (http://cetsound.noaa.gov; Figure 2-2).



Marine Geospatial Ecology Lab, Duke University (2012)

Figure 2-2. Predicted low frequency (one-third octave centered at 100 Hz) average annual noise levels (equivalent, unweighted sound pressure level in decibels re 1 µ Pa) at 30 m depth, summing contributions from a variety of human activities (see http://cetsound.noaa.gov/sound_data) within the US Exclusive Economic Zone (brown lines).

As NOAA looks to integrate acoustic habitat protection within its science and management activities, it is helpful to examine which tools developed to support the agency's traditional, species-based noise impact evaluation processes can be leveraged to inform broader evaluation of impacts to acoustic habitats. Noise impact assessments, whether addressing direct effects to individual animals or degraded acoustic habitat, share basic science needs. Chief among them are to identify: (1) which species use or make sound (including hearing, sound production, and sensitivity); (2) the role of sound in their life histories (acoustic ecology and behavior); and (3) how they use their environments (including their distribution and habitats that support biologically important activities, such as reproduction and feeding). However, NOAA's historical focus on tissue damage and behavioral response has underemphasized additional science needs that would inform understanding of the consequences of anthropogenically-altered acoustic habitats. For example, more research is needed to characterize variation in the production or perception of intraspecific communication signals in natural areas with different background noise conditions. Likewise, more research is needed to better document the quietest signals that animals can (and do) perceive in the wild. Recent investments in the development of models to interpret the consequences of behavioral responses to noise (e.g., Population Consequences of Disturbance; SMRU Consulting 2015) have the potential to, but have yet to, address the long-term effects on the viability of populations when individuals are less able to hear conspecifics, prey, predators, or key environmental awareness cues. There is a clear need to ensure that such modeling can address data-poor as well as data-rich management contexts. Tools that are being adapted to implement ecosystem-based management of fisheries (e.g., Productivity-Susceptibility Analyses; Food and Agriculture Organization of the United Nations 2015) allow for rapid risk assessment when faced with uncertainty regarding ecological relationships as well as population demographics. Such techniques could generate estimates of risk for individual populations and ecosystems due to noise-altered habitat or displacement from habitat due to noise, and could integrate risk associated with multiple threat types.

Place-based risk assessments are a particularly useful framework for integrating multiple data resources in order to inform agency decision-making. Characterizations of the co-occurrence of high-value target species, high-value target places, and predicted and measured noise levels can inform agency actions at several scales (Erbe et al., 2014, Redfern et al., submitted). In some cases, current passive acoustic monitoring and noise modeling capacity may be sufficient to support NOAA's assigning high risk to a high-value acoustic habitat that is currently quiet when compared to other areas, and where action is necessary to maintain lower noise levels. In other cases, high risk may be associated with a high-value habitat that is currently relatively loud and where action is necessary to reduce noise levels. Given the status of standardized long-term passive acoustic monitoring and noise modeling capacity in U.S. waters today, however, available data may or may not be sufficient to support mitigation design (i.e., identification of dominant noise contributions at various spatial, temporal and spectral scales). NOAA's actions to strengthen protection for high-risk acoustic habitats will therefore need to be adaptive, continually improving both the design and implementation of effective mitigation.

NOAA's Tools for Managing Acoustic Habitat

Historically, NOAA has managed the impacts of noise on its trust resources by using legal frameworks designed to protect target populations and species. These populations and species are those that society has determined need special care, including those that are endangered or threatened, and those that are of particular ecological, cultural or economic interest, including all marine mammals. The Endangered Species Act (ESA 1973) and the Marine Mammal Protection Act (MMPA 1972) are the primary statutes by which NOAA requires mitigation strategies and monitoring action designed to reduce or eliminate and better understand the impacts that specific types of noise have on this limited suite of species. Under these statutes, management action has focused on reducing the potential for relatively loud noise sources (e.g., airguns, sonars, pile drivers) to unambiguously injure animals or cause them to respond behaviorally over (usually) relatively small spatial and temporal scales. This traditional approach has played an important role in fulfilling NOAA's stewardship mandates by preventing or minimizing acute harm to individual animals.

The U.S. National Ocean Policy (U.S. NOP; Executive Order 13547 2010), however, firmly directs federal agencies to implement ecosystem-based approaches to management. Fundamentally place-based, these management efforts seek to conserve functioning ecosystems and the services they provide. Ecosystem-based management approaches highlight the importance of natural habitats and parallel additional efforts within NOAA to focus the agency's many mandates to protect and restore habitats. Inherent in these policy directives is the need for NOAA to begin to address the widespread degradation of natural acoustic habitat for a broad range of acoustically-sensitive species due to increasing noise from accumulated anthropogenic sources.

The degree to which NOAA's management tools can be used to focus on specific habitats ranges widely. Many, but not all, areas managed or co-managed by NOAA meet the national definition of a marine protected area (MPA). In the U.S., an MPA is broadly defined as "an area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (Executive Order 13158 2000, Section 2(a)). Covering over half the total area of the U.S. Exclusive Economic Zone (EEZ) and occupying most habitat types (Table 2-1), U.S. MPAs have been established by a variety of federal, state, and tribal agencies to protect a diversity of species (e.g., mammals, fish, invertebrates, and plants), cultural resources, and natural ecosystem features and processes. MPAs in the U.S. also vary widely in their conservation purposes, and in the associated level, scale and permanence of protection afforded the resources they protect (Table 2-1, categories discussed in National Marine Protected Areas Center 2011). NOAA manages or co-manages only 13% of MPAs within U.S. waters. However, these 13% represent 99% of the total area contained within U.S. MPAs. This is due mainly to the existence of many large Sustainable Production fishery MPAs, a few large marine mammal MPAs on the East Coast and 4 large Marine National Monuments in the Pacific. While two-thirds of U.S. MPAs have a broad ecosystems conservation focus, two-thirds of NOAA MPAs focus on the conservation of specific focal resources. The remaining one-third of NOAA MPAs, including fifteen sites managed by the Office of National Marine Sanctuaries, focus on comprehensively protecting marine ecosystems. Regardless, as the main federal managers of large, offshore MPAs, NOAA plays a key role in shaping and executing U.S. marine spatial protection.

Table 2-1. Prevalence and diversity of management approaches for all existing Marine Protected Areas (MPAs) in U.S. Exclusive Economic Zone (EEZ) waters, as well as National Oceanographic and Atmospheric Administration (NOAA)-managed or co-managed areas.

	All U.S. MPAs		**NOAA MPAs**	
	Number	Percent	Number	Percent
MPA Area Coverage in U.S. EEZ				
Number of MPAs in U.S. EEZ	1,774	--	227	13%
U.S. EEZ area covered by MPAs	6.85M km2	55%	6.78M km2	99%
Primary Conservation Focus of U.S. MPAs (#'s of sites)				
Natural Heritage	1,179	67%	80	35%
Sustainable Production	442	25%	145	64%
Cultural Heritage	153	9%	2	1%
Level of Protection of U.S. MPAs (#'s of sites)				
Uniform Multiple Use	1,402	79%	187	82%
Zoned Multiple Use	111	6%	21	9%
Zoned w/ No Take	35	2%	6	3%
No Take	127	7%	13	6%
No Impact	16	1%	0	0%
No Access	83	5%	0	0%
Ecological Scale of Protection (#'s of sites)				
Focal Resource	674	38%	164	72%
Ecosystem Scale	1,100	62%	63	28%
MPAs Managed by NOAA Line Office (#'s of sites)				
NOAA Fisheries	182	10%	182	80%
National Ocean Service	45	3%	45	20%

A fuller understanding of how and where NOAA's existing spatial management tools can be used to sustain viable acoustic habitats will help the agency meet and adapt to the growing threat ocean noise poses to our trust resources. NOAA's place-based tools can generally be categorized as those that are applied by the agency to fulfill mandates to protect specific, high-value populations or species, versus those that are applied towards protecting a high-value area, including all its attributes (Table 2-2). Here, we use the term "high value" to generalize the many statute-specific definitions that are used to identify the specific populations, species and areas that NOAA is mandated to protect (e.g., endangered or commercially important). The tools listed here include only those with links to NOAA's statutory authorities or actions. Marine National Monuments, for example, are not de-facto included in this table, as their designation under the Antiquities Act (1906) is an act of the President not the Agency, and doesn't in and of itself, provide NOAA with additional statutory authorities to support management goals. That said, the NOAA National Marine Fisheries Service's Marine National Monument Program serves to coordinate the development of management plans, scientific exploration and research programs under their existing authorities (MMPA, ESA and Magnuson–Stevens Fishery Conservation and Management Act-MSFCMA 1996) within all four of the Marine National Monuments in the Pacific Islands Region. In addition, NOAA's Office of National Marine Sanctuaries, with authorities under the National Marine Sanctuaries Act (NMSA 1992), has active management roles within two Marine National Monuments, Papahanaumokuakea and Rose Atoll.

The tools listed are not exhaustive of NOAA's authorities, but provide examples of different types of measures within the agency's jurisdiction that are currently or could in the future be applied to address noise impacts to acoustic habitat. Some authorities have operational areas that can authorize NOAA actions over very large areas, encompassing the full geographic range of target populations, species or their habitats. Cetacean Biologically Important Areas were identified for certain cetacean species through NOAA's CetMap program (Van Parijs et al., 2015a), and are included here despite their lack of statutory authority due to NOAA's role in supporting their development and their direct link to NOAA's noise impact assessment activities. Similarly, several new tools that support increasing attention by the agency to ecosystem-based management are listed in the table. Although many are in early stages of development and are not accompanied by new statutory authorities, they represent promising new mechanisms for focusing agency attention towards restoration or enhanced protection of high value aquatic places (e.g., Habitat Blueprint Focal Areas, NOAA Fisheries 2015a, Important Ecological Areas, Northeast Regional Planning Body 2015). Finally, several tools that authorize NOAA to provide technical expertise to other state or federal decision-making processes are listed, due to the roles that such influence could play in broadening the scope of NOAA's direct actions.

Scales of applicability (spatial, temporal and ecological) are considered for each tool, in order to examine their limitations and strengths for addressing acoustic habitat management goals. Potential noise management outcomes are classified generally as influencing either mitigation or monitoring of noise exposure for target taxa or areas. Mitigation includes actions taken to reduce the occurrence of noise impacts. Here, monitoring specifically addresses measurements taken during noise-producing activities (required of those promoting the activity) in order to evaluate potential for impact that may or may not occur, and the information gained can inform future management decisions. In addition, NOAA has a variety of statutory mandates that support the agency's own need to monitor noise impacts on the populations, species, and areas it manages. Those measures are not listed here, nor are more general National Environmental Policy Act (NEPA 1969) mandates that direct all federal agencies to evaluate environmental impacts of proposed activities, including noise impacts, to trust resources. These self-directed mandates can be used to strengthen the agency's actions towards acoustic habitat management priorities.

Table 2-2. Examples of place-based tools that NOAA is or could be applying to acoustic habitat science and management goals, assessed relative to their statutory authorities, scopes (spatial, temporal and ecological) and outcomes.

Objective of NOAA's Place-Based Management	NOAA Examples	Relevant NOAA Statutory Authorities[1]	Spatial Scale	Temporal Scale	Ecosystem?	Role for NOAA Acoustic Habitat Science	Role for NOAA Acoustic Habitat Management
Measures aimed at protecting aquatic animal populations or species of high value	Endangered Species Recovery Plan and Marine Mammal Conservation Plan action areas	MMPA; ESA	Geographic range of species including everything but foreign territorial waters	long-term	No	Can require monitoring	Could influence wide-ranging noise mitigation by multiple US agencies and Internationally (e.g., quieting design implementation)
	Fishery Management Plan action areas	MSFCMA	Geographic range of species including US rivers and estuaries, coasts, Continental Shelf and EEZ[2]	long-term	No[3]	Could require monitoring	
	Essential Fish Habitat	MSFCMA	Geographic range of species including US rivers and estuaries, coasts, Continental Shelf and EEZ	Variable: long-term (planning) and project-by-project (interagency consultation)	No	Can recommend monitoring	
	Incidental Take Authorization mitigation zones; Interagency consultation action areas	MMPA; ESA	Varible project-by-project, mostly sub-regional; everything but foreign territorial waters	Variable: long-term (some consultation); short term (most consulation and all permitting)	No	Must require monitoring	Can require mostly sub-regional scale, short term mitigation
	Cetacean Biologically Important Areas (CetMap)	Various: MMPA, ESA, NMSA, CZMA, etc.	Variable; sub-regional; US rivers and estuaries, coasts, Continental Shelf and EEZ	TBD	No	Could influence regional-scale long-term monitoring	Could influence regional-scale long-term mitigation
	Endangered Species' Critical Habitat	ESA	Variable; sub-regional; US rivers and estuaries, coasts, Continental Shelf and EEZ	Variable: long-term (planning) and project-by-project (interagency consultations)	No	Can require monitoring	Can require short-term (most consultation) and influence long-term (som consultation, planning) mitigation
	Habitat Areas of Particular Concern (Essential Fish Habitat)	MSFCMA	Variable; sub-regional; US rivers and estuaries, coasts, Continental Shelf and EEZ	Variable: long-term (planning) and project-by-project (interagency consultations)	No	Can recommend monitoring	Can recommend noise mitigation
	Fish and Wildlife Coordination Act and Federal Power Act action areas	FWCA, FPA	Natural streams and inland bodies of water used by migratory, estuarine and marine fishes	Project-by-project	No	Could influence consideration of monitoring by other federal agencies[4]	Could influence consideration of mitigation by directed federal agencies[4]
	Anadromous Fish Conservation Act action areas	AFCA	Great Lakes and Lake Champlain (Columbia River Basin) streams used by spawning fish	long-term	No	Could influence consideration of noise monitoring by states	Could influence consideration of noise mitigation by states
	Fishery Community Based Restoration Program action areas	MSFCMA	US rivers or estuaries used by spawning anadromous fish species	long-term	No	Could influence monitoring	Could influence mitigation
Measures aimed at protecting aquatic areas of high value	Regional Marine Planning areas	Various: MMPA, ESA, NMSA, MSFCMA, CZMA, etc.	Eight US regions that include territorial sea, EEZ and Continental Shelf landward of mean high-water line, inland bays and estuaries (additional inland waterways TBD)	long-term	Yes	NA--not yet established	NA--not yet established
	Habitat Blueprint Focal Areas	Various: MMPA, ESA, NMSA, MSFCMA, CZMA, etc.	Boundaries of designated sites (though serves to coordinate activities with adjacent/influencing areas)	long-term	Yes	NA--planning phase; could influence monitoring plans	NA--planning phase
	National Resource Damage Assessment action areas	OPA	Areas where NOAA-managed resources and they services they provide are damaged by release of oil or other hazardous substances	Incident specific	Yes	Could influence monitoring	Could influence mitigation
	Coral Reef Conservation Program action area	CRCA	US jurisdictions and waters with shallow-water coral reefs	long-term	Yes	Could influence monitoring	Could influence mitigation
	Coastal Zone Management Planning areas	CZMA	All territorial US waters and adjacent land areas	long-term (enhancement programs); Project-by-project (federal consistency)	Yes	Can influence consideration of monitoring by states	Can influence consideration of mitigation by states
	National Estuarine Research Reserves	CZMA	Boundaries of designated sites	long-term	Yes	Could influence consideration of monitoring by site lead (state or university)	Could influence consideration of monitoring by site lead (state or university)
	National Marine Sanctuaries	NMSA	Boundaries of designated sites (but including activities occurring outside sites that cause injury within sites)	long-term (management planning); Project-by-project (permitting of prohibited activities and interagency consultation)	Yes	Could require (permitting) and can recommend (planning, consultation) monitoring	Could require (permitting) and can recommend (planning, consultation) mitigation

[1] Marine Mammal Protection Act, Endangered Species Act, Magnusen-Stevens Fishery Conservation and Management Act, Fish and Wildlife Coordination Act, Federal Power Act, Anadromous Fish Conservation Act, Coastal Zone Management Act, National Marine Sanctuaries Act, Oil Pollution Act and Coral Reef Conservation Act; [2]Exclusive Economic Zone; [3]Plans in process have ecosystem focus; [4]US Fish and Wildlife Service, US Army Corps of Engineers and Federal Energy Regulatory Commission

THE PATH FORWARD

NOAA has embarked on a path to better understand the importance of sound in marine ecosystems, and to more effectively manage anthropogenic threats to acoustic habitats using both current and improved tools. Growing threats from noise to acoustically sensitive species coupled with limited agency resources needed to address these challenges suggest a need to simultaneously move forward aggressively while making clear strategic decisions about where and how to prioritize those efforts in the coming years. While specific decisions in the future will be influenced by many factors, the following actions seek to match the broad spatial and long temporal ecological scales over which noise is impacting acoustic habitats.

Create and Support International Initiatives to Reduce Influence from Distant Noise Sources

NOAA acknowledges that addressing chronic noise conditions within some acoustic habitats of concern will necessitate management action that can reduce noise exposure over very large spatial scales (McCarthy 2004, Hatch & Fristrup 2009). Drivers for wide-ranging mitigation solutions stem from both presumed species-specific communication ranges (e.g., fin and blue whales) and documented propagation distances for low frequency noise sources (e.g., seismic airguns and ships). Distant sources of noise will have differential impacts within acoustic habitats of interest. In general, deep water habitats in northern hemisphere mid-latitudes or highly trafficked seas are likely to be significantly influenced by wide-ranging noise sources (National Research Council of the U.S. National Academies 2003). Additionally, many highly migratory populations of endangered baleen whales are known to produce low frequency calls and songs throughout most of their ranges (e.g., Charif et al., 2001, Oleson et al., 2014). Acoustic conditions could be considered relevant to these species wherever they occur. NOAA's authorities for addressing range-wide threats to target populations and listed species often explicitly recognize and direct multilateral approaches (e.g., Endangered Species Recovery Planning). Such drivers provide important mechanisms for the agency to engage in long term, international efforts to reduce chronic noise influence, in addition to more nationally-focused activities.

Efforts to recover, restore, and ensure sustainable harvest of species over large ranges necessitate partnerships with other agencies and countries, and industries with direct mechanisms to influence implementation of quieting programs. NOAA has provided leadership for such efforts to develop technical guidelines to reduce noise from commercial ships through the United Nations' International Maritime Organization. In partnership with the U.S. Coast Guard, NOAA supported the U.S.'s chairing of these efforts beginning in 2008, with successful passage of guidelines in 2014 (International Maritime Organization 2014). NOAA continues to work with inter-agency and non-governmental partners to support international implementation of these guidelines. Key next steps include pilot programs for select shipping companies and, ideally, select ports, with interests in supporting "green ship" development, in which new ships are built or existing ships are modified to include quieting in design and operational goals. Pilot programs would evaluate time horizons for cost-recovery (e.g., via increased fuel efficiency, reduced maintenance etc.), consider integration of quieting goals with other environmental protection goals included in green ship design projects, and develop monitoring and docking incentives associated with participating ports.

NOAA has been less directly engaged in international efforts to encourage the development of quieter technologies to modify or replace other dominant low-frequency noise sources, like airguns, other seismic sources, pile-driving activities, and vessel dynamic positioning systems that are used in a wide-variety of offshore energy development phases (e.g., exploration, platform construction, extraction/generation). For such sources, NOAA's current regulation and consultation activity to address physical and behavioral effects due to acute noise exposure focuses on noise reduction techniques to reduce peak pressures or short term (e.g., one day) accumulated energy experienced by animals swimming nearby (e.g., some pile-driving sound attenuation techniques). Broadening such designs to address lost listening opportunities over larger spatial and longer temporal scales will necessitate setting of engineering targets that reference biological effects at those scales. Longer-term effect targets are emerging from modeling the population-level consequences of displacing harbor porpoises from their habitat in the North Sea as a result of regional wind farm development (SMRU Consulting 2015). However, effect targets assessed via modeling of consequences mediated through full ecosystems are also important, to ensure that species-specific noise optimizations benefit habitat conditions more holistically. Many of the companies conducting noise-producing activities in support of offshore energy exploration and production have increased their investment in quieting technologies, recognizing that quieter alternatives would be environmentally preferable and would reduce the complexity of operating within highly variable international regulatory constraints. For example, a wide range of international oil companies and the International Association of Geophysical Contractors continue to invest in the development of marine vibroseis technology as an alternative to airgun technology for use in seismic data acquisition (E&P Sound & Marine Life Joint Industry Programme on Sound on Marine Life 2015).

Improve and Apply National Tools to Reduce Cumulative Impacts

Given the increasing number of noise-producers seeking permits from NOAA to authorize impacts, there is a need to address the implications of accumulated exposure to acoustic habitats. This need is not isolated to noise among environmental stressors, nor to the U.S. alone. Tools to address cumulative, multi-source effects over wider spatial scales are emerging in the European Union associated with the implementation of Marine Strategy Framework Directive (EU MSFD). The EU MSFD defines its objective, Good Environmental Status, to include the requirement that "Introduction of energy (including underwater noise) does not adversely affect the ecosystem" (EU MSFD 2008). Regional registries of noise-producing events, developed by individual countries (e.g., UK and The Netherlands) but with high levels of multi-lateral collaboration, are being used to characterize contributions to national and regional noise budgets. Importantly, these registries collect information regarding nationally-permitted noisy activities both at the times they are proposed and then again after they are completed. Such registries thus allow European countries with collective, regional interest in regulating noise to describe relative, actualized noise contributions to localized acoustic habitats of concern. Noise predictions based on registered events can be compared to monitoring data to estimate remaining contributions from non-registered source types.

A geospatially-explicit registry of all federally authorized (i.e., NOAA permitted and/or requiring non-NOAA federal action) noise-producing events in U.S. waters would inform many facets of NOAA's activities to address cumulative noise impacts to high risk acoustic habitats. In parallel with EU MSFD efforts, such a registry would inform NOAA's role in implementing the U.S. National Ocean Policy. The U.S. National Ocean Policy encourages Regional Marine Planning as "a science-based tool that regions can use to address specific ocean management challenges and advance their economic development and conservation objectives" (National Ocean Council 2013a, p. 21). Regional Marine Planning Bodies have been established in several U.S. regions, with the northeast and mid-Atlantic regions the furthest advanced towards finalization of Regional Marine Plans. Several Regional Planning Bodies (as well as similar regional collaboratives) have invested in mapping coastal and offshore human use patterns as critical information to inform discussions of compatibility among uses and to achieve ecosystem protection goals. Some noise producing activities are likely well-captured by current mapping initiatives, including the likely influence of ocean-going (e.g., cargo, tanker) and some more localized commercial (e.g., fishing, ferries, tug-tow) and recreational (e.g., fishing, pleasure) vessels on regional acoustic habitats (e.g., SoundMap, http://cetsound.noaa.gov/sound_data). Others are captured in more generalized and often low-resolution projected terms, including levels of expected activity within boundaries of lease blocks for energy development or ranges for military activities. Higher resolution information describing actualized activity levels evaluated after they occurred would significantly improve place-based characterization of noise contributions in areas with high federal authorization activity.

In other areas, improving noise estimates will demand approaches that account for activity types that are not federally authorized. In particular, noise in nearshore waters can be influenced by a diversity of human activities that may or may not require local, state, tribal or federal authorizations, including offshore communication and energy installations, port and harbor operations, maintenance of bridges and waterways, pleasure craft, and even onshore road traffic. Inshore areas are often of high concern for environmental management (Table 2-2), as they support biologically important (and often acoustically sensitive) reproductive and early life stage behaviors for a wide range of aquatic taxa, including invertebrates, fish and mammals. Measurements of coastal noise levels are increasingly collected by nearshore monitoring efforts, although they disproportionally sample locations and time periods that contain noisy events and are often not regionally centralized. A new land-based modeling technique would, however, leverage the increasing quantity and spatial coverage of coastal noise measurement data and shows great promise for improving the accuracy and accessibility of noise predictions over large scales. This technique has been applied to relate well-distributed noise measurement data to geospatial datasets that describe key anthropogenic, biological and geophysical predictors of noise, generating maps of noise levels that span the U.S. continental states (Mennitt et al., 2014, http://www.nature.nps.gov/sound/soundmap.cfm). Although necessitating continual improvements in noise measurement databases, this technique reduces reliance on high resolution descriptions of noisy activities. Such regional to coast-wide noise predictions would improve representations of cumulative conditions within both Coastal Zone Management and Regional Marine Plans. States with approved Coastal Zone Management Plans can then determine whether federal actions or permits associated with proposed activities are consistent with the enforceable policies of their plans (Coastal Zone Management Act 1972, see Table 2-2). While Regional Marine Plans may not explicitly seek to reduce accumulated noise impacts within high-risk acoustic habitats, such an outcome is inherent to planning objectives that seek to reduce regulatory burdens for both NOAA and those promoting noise-producing activities by improving information regarding place-based cross-sectoral and environmental compatibility (National Ocean Council 2013b).

Marine planning seeks to support statutorily-directed consultation and environmental impact assessment processes that are standardly used to address noise impacts (Table 2-2). Registries of federally permitted noise-producing events would allow NOAA, in concert with long term monitoring capabilities, to guide project-specific consultation activity under the ESA, NMSA and MSFCMA towards longer-term mitigation designs to address noise sources that are identified as being dominant contributors to both accumulated acute and chronic noise in high risk acoustic habitats. In addition, “programmatic” NEPA evaluations and consultations are increasingly being performed by agencies with direct regulatory responsibility for noise-producing activities (Council on Environmental Quality 2014), often in partnership with NOAA. These actions seek to assess implications for populations, species and places over regions and multi-regions and over multi-year time periods. Cooperative evaluation of environmental consequences, including noise consequence, of longer-term and wider-ranging activity is improving interagency information sharing and supporting the development of new tools to support risk assessment at these scales. Such tools would benefit from interagency cooperation to generate and contribute to registries of noisy events, and particularly to improve information regarding actualized versus proposed activity profiles. Programmatic impact assessments and consultations also have the potential to improve characterization of noise budgets within acoustic habitats of management concern through longer-term monitoring requirements.

Finally, improved characterizations of accumulated noisy activity would support NOAA's decisions regarding use of the agency's statutory authorities to strengthen localized protection for acoustic habitats. NOAA has applied its generalized authorities under the MMPA and ESA (Table 2-2) to regulate ship speeds in areas and during time periods when risks of collision with North Atlantic right whales are heightened. These regulations thus applied range-wide authorities to direct long-term, though more spatially restricted, mitigation in targeted areas. Monitoring required to support this action has in turn supported better understanding of collision risk, as well as measuring compliance and informing enforcement actions as necessary. Such generalized authorities are available to the agency within several statutes, and provide opportunity for establishing long-term mitigation (e.g., seasonal or year-round exclusion or reduction in noisy activity levels, use of quieter technology) in a high risk acoustic habitat. Such actions must be supported by a needs analysis documenting the detrimental (although mostly sub-lethal) consequences of the noise source(s) that will be mitigated, on targeted NOAA-managed resource(s), included in the "basis and purpose" of the rulemaking. In addition, NOAA's support for the development of Cetacean Biologically Important Areas has identified places, additional to those defined as critical for ESA-listed species, to inform management action across the many permitting and consultation actions currently being taken to address noise impacts on these species. Just as these areas will be modified in the future to reflect additional scientific information, their application to management actions should be evaluated over time to determine whether they are effective in enhancing the condition of the acoustic habitats they contain. Long-term monitoring within biologically important areas and critical habitats associated with highly vulnerable and acoustically sensitive cetacean populations (e.g., Southern Resident Killer Whales, North Atlantic Right Whales, Cook Inlet Beluga Whales) will be critical to establishing baselines for assessing success of multi-action mitigation, and determining whether existing or additional place-based management authorities are or would be effective.

Realize the Potential of National Marine Sanctuaries

The activities discussed above seek to address wide-ranging, repeated, and long-term noise exposure by leveraging NOAA's species- and habitat-specific authorities to achieve noise reduction benefits within acoustic habitats where target species co-exist with many other acoustically-sensitive and active species. They also seek to interface with ecosystem-protection frameworks such as NOAA's Habitat Blueprint effort and the U.S. NOP. National Marine Sanctuaries, however, represent key NOAA assets to achieve the ecological goals of acoustic habitat protection, due to their mandate to protect whole and functioning natural ecosystems (Table 2-2). Given the importance of sound to survivorship and well-being of diverse marine species and ecosystems, this ecosystem protection mandate extends to ecologically-important environmental characteristics like sound and thus to the maintenance or restoration of viable acoustic habitats for a range of acoustically sensitive species that inhabit sanctuaries. Preserving, restoring, and maintaining natural acoustic habitats within sanctuaries is a complex endeavor, involving the development of new scientific capabilities, new management measures and processes, and outreach programs.

Currently, only 4 National Marine Sanctuaries (Stellwagen Bank, Olympic Coast, Cordell Bank and Channel Islands) are operating long-term passive acoustic monitoring systems. Other sites do so periodically or are developing longer-term soundscape research programs in partnership with academic institutions. The Office of National Marine Sanctuaries is seeking to enhance these capabilities in collaboration with NOAA's Pacific Marine Environmental Laboratory, NOAA Fisheries, and the U.S. National Park Service (NPS) through the development of the NOAA Noise Reference Station Network (NOAA Fisheries 2015b). The maturation of the Natural Sounds and Night Skies Division within the NPS has showcased the importance of developing system-wide, standardized, calibrated and long-term noise measurement capability to support site-based but coordinated noise management objectives (Hatch & Fristrup 2009). At Stellwagen Bank National Marine Sanctuary, where passive acoustic monitoring has more longevity, higher-resolution research focuses on characterizing acoustic variability among different habitat types, continuing to document species-specific acoustic behaviors, and identifying environmental signals of relevance to sanctuary species.

While management of acoustic habitats in protected areas, both terrestrial and aquatic, is relatively new to environmental protection activity, National Parks have been operating under defined soundscape management policies for over a decade (NPS 2000, 2006). Key lessons have emerged that should be taken into account as National Marine Sanctuaries seek to digest acoustic habitat status and trend information in order to characterize effects and establish objectives for threat reduction. The development of metrics is a controversial step in environmental threat management. Both NOAA and NPS have learned that thresholds, in and of themselves, become short-hand for representing the agency's broader perspective for how noise influences wildlife. Thus, effect metrics should identify and communicate protection targets associated with acceptable levels of biological effect, rather than the levels of noise that are predicted to produce those effects. For example, parks have been successful in translating information regarding noise influence within their soundscapes into metrics of acceptable or unacceptable levels of communication interference, sleep disturbance and lost listening capability (NPS 2010). Such metrics are relatable to people (e.g., visitors and managers) as well as park wildlife, and synthesize impacts associated with many types of noise exposure (e.g., rare sudden loud events, accumulated disruptive noise events and continuous background noise).

The National Park soundscape management experience further suggests that sites within a system may or may not share effect level targets for management. Variation among sites in effect reduction or maintenance objectives will be driven by a range of factors, including, but not limited to, the status of natural and human contributions to their soundscapes and prioritization of noise protection relative to other managed threats. However, long-term management action must reference site-specific estimates of pre-industrial levels as baselines for interpreting progress towards biologically-relevant recovery. The reference condition for park soundscape management is clearly specified to be the historical, noise-free environment (NPS 2006, section 8.2.3). Sanctuary management should recognize the importance of measuring or estimating anthropogenic noise-free acoustic habitat conditions to calibrate incremental protective action both within sites as well as among sites.

Achieving noise management goals within National Marine Sanctuaries will require multi-faceted action. Some sources of distant propagating noise, as discussed above, will require international as well as other domestic activity. However, proposed activities that may (Stellwagen Bank) or are likely to (all other sanctuaries) result in injury to sanctuary resources are required to consult with NOAA (see Table 2-2). This requirement includes activities that are and are not prohibited from occurring within specific sanctuaries and it includes activities occurring outside sanctuary boundaries from which injury inside sanctuary boundaries may occur, as is often the case with noise. NMSA consultation results in recommendations to action agencies, not binding requirements; however, the recommendations carry liability associated with rejection, and they offer the potential for structured, long-term dialogue between NOAA and other federal agencies, as well as with the public, regarding acoustic habitat management goals and suggested mitigation to achieve those goals. Consultation authority can also incentivize stakeholders to invest in promising new mitigation techniques that could be used in proximity to sensitive or protected sites, including sanctuaries. The application of consultation authority to address noise impacts within sanctuaries is growing exponentially, but is currently limited by staff capacity. NOAA's overlapping authorities within sanctuaries provide additional opportunities to broaden the protective value of sanctuaries. Most sanctuaries protect resident or seasonal marine mammals, or endangered and threatened species, or commercial and recreationally important fish species and their essential habitat. In some cases, intra-agency consultations provide opportunities for NOAA to evaluate the noise implications of its own actions (e.g., issuance of Incidental Harassment Authorizations under the MMPA) on a sanctuary resource, providing opportunities for the agency to coordinate and strengthen its protective capabilities for specific species within these sites. Such opportunities are also increasingly being identified, but again are limited by staff capacity.

Finally, but perhaps most importantly, sanctuaries are a vital NOAA asset for building new constituencies to protect our coasts and oceans and for ensuring that people understand the role of sound and hearing to the healthy functioning of aquatic places. Sanctuaries, like parks, provide places for local conversations among people with different views about what is important to them about the current and future condition of their ocean. These conversations expose people to new scientific information regarding environmental effects as well as more nuanced perspectives on the practices of industries. Like air and water, the acoustic environment can be polluted and, in the 1970s, the U.S. recognized noise as an environmental pollutant that necessitated regulation to protect human health (Noise Control Act 1972). But the protection of the holistic acoustic conditions that wildlife, and particularly animals that live underwater, need in order to survive and persist is only recently recognized as warranting international re-investment. Sanctuaries represent opportunities to educate current and future generations about the importance of natural acoustic habitats and what can be done to reduce the influence of noise on these habitats.

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Enhancing NOAA's Ability to Characterize Aquatic Soundscapes

INTRODUCTION—SOUNDSCAPES AND THE SOUNDS THAT COMPRISE THEM

A soundscape can be thought of as the aggregate collection of all of the sounds (both natural and anthropogenic) that occur or are received at a particular location making up the total acoustics of a place (Chapter 2). Sounds that occur within a soundscape can be of either natural or anthropogenic origin, with natural sources of sound further divided into biotic (biological) and abiotic (physical) sources. Collectively, these three categories of sound sources, the biophony (natural biological), geophony (natural physical), and anthrophony (man-made) (Pijanowski et al., 2011), comprise the soundscape of a particular location.

In marine and freshwater environments, natural sounds comprising the biophony include those produced by animals that reside underwater, and can range in frequency from a deep, low-pitched 10 Hz to extraordinarily high pitched, ultrasonic sounds over 200 kHz. In marine soundscapes, these sources include fish, seabirds, marine mammals, and invertebrates which use sound to perform critical life functions. Natural abiotic sounds comprising the geophony are produced by the physical environment. These sound sources include weather-generated sounds from rain, lightning strikes, wind, and breaking waves on the water's surface, movement of ice, water, or sediments, tectonic or geo-seismic activity like volcanic eruptions or earthquakes, and any other naturally occurring abiotic process which creates sound within the marine environment.

Anthropogenic sounds comprising the anthrophony, on the other hand, are sounds from human activities introduced into the natural environment. Anthropogenic sounds in underwater soundscapes include noise from transportation and vessels, oil and gas exploration, drilling and production, construction and dredging activities, fishing activity, echosounders, geophysical surveys, military activities including sonar, explosions, and many other human activities. In the aquatic realm this category of underwater noise did not exist prior to the advent of the industrial age. By their very nature, therefore, the introduction of these man-made sources of sound into the aquatic environment alters soundscapes from their natural and historical states.

THE NEED TO UNDERSTAND AND CHARACTERIZE SOUNDSCAPES

The ocean is an inherently noisy place. Historically, it has been filled with the cacophony of sounds, including those produced by animals, wind, rain, ice, and geologic activity among the many other sources noted above. These natural sounds have been present throughout long evolutionary time scales; over millions of years, animals have existed, evolved, and adapted to the natural underwater acoustic environment. Unlike other potential means of communication (e.g., visual, chemical, tactile), in the ocean sound propagates with great speed to great distances (e.g., Munk et al. (1994) demonstrated low frequency sounds can travel across and between multiple ocean basins in a matter of hours). The production and reception of sound is an incredibly efficient means of communicating over distance. Marine animals, therefore, have evolved over millions of years to rely on sound as a primary means of communication, and gaining information about and interacting with the environment in order to be able to survive and reproduce.

Importance to NOAA's Understanding of Species and Places

The soundscapes in a particular location, and the acoustic habitats (Chapter 2) of the animals inhabiting it, vary temporally, over both short- and long-time intervals, with tidal, diel, seasonal, and annual cycles in signals present, and also across frequencies with sounds from different sources occupying different portions of the acoustic spectrum (Figure 3-1). Soundscapes and acoustic habitats may also vary greatly geographically. Between nearby locations, the lower frequency (i.e., deeper pitch) portion of the soundscapes may be similar due to the greater ability of low-frequency sound to travel long distances, while the higher frequency portion may be distinctly different, since these sounds are attenuated much more quickly and are therefore more site-specific. Between two distant locations, or locations in different environments (e.g., open water vs. enclosed bay), the soundscapes may be entirely different across the frequency spectrum. Soundscapes may even vary with depth due to the sound propagating characteristics of the water column. In order to understand how soundscapes and acoustic habitats vary in different environments, locations, and depths, how animals' utilize sound to carry out critical life functions, and the variety and levels of sounds an animal may experience and respond to throughout the world's ocean, accurate characterization of the underwater soundscape is essential.

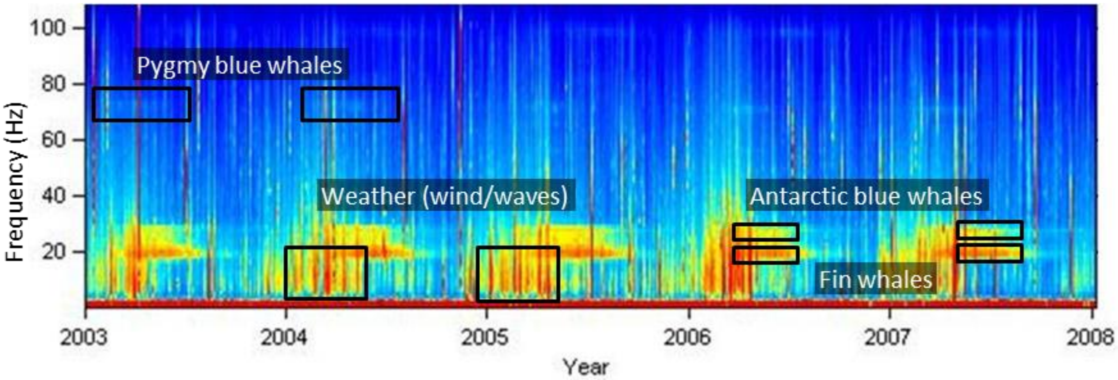


Figure 3-1. Long-term spectrogram (5 years) illustrating repetitive seasonal changes in the soundscape, due to weather, and singing Antarctic and pygmy blue, and fin whale populations south of Australia. Data is from the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) passive hydroacoustic monitoring station off Cape Leeuwin, Australia.

Understanding of Anthropogenic Changes to Soundscapes

The introduction of anthropogenic noise into the ocean effectively began with the advent of the industrial age less than 200 years ago, with the most rapid increase in noise-producing human activities occurring over just the last 50-75 years. From steam engines and the development of propeller-driven ships, to massive levels of shipping, oil and gas exploration, and industrial activity, man's acoustic footprint in the ocean has become more and more widespread. Even in relatively pristine oceanic habitats like the Southern Ocean surrounding Antarctica, the sounds of man's distant activities can often be heard.

Such a rapid change in the underwater acoustic environment and animals' acoustic habitats, an instant on evolutionary time scales, has the potential to affect ecosystems and animals in a multitude of complex ways that we are only just beginning to appreciate. The effects of introduced noise may manifest themselves through a range of acute, chronic, and cumulative effects of multiple noise sources and other stressors (See Chapters 1 and 2, Appendix A). The consequences of these potential impacts include those that are immediate and obvious (e.g., masking leading to missed detection and avoidance of a predator), to more incremental and cryptic effects (e.g., increased stress levels, missed feeding or breeding opportunities). The accumulation of cryptic effects over long periods may ultimately result in detrimental effects on the individual, which can impact the recovery, growth, or stability of a population, or ecosystems that they inhabit. In both cases, an ability to accurately characterize the contributions of natural and human sources to soundscapes is an essential step to understanding the ways that aquatic animals utilize sound and how man-made noise may potentially impact them.

CHARACTERIZING MARINE SOUNDSCAPES

Marine soundscapes can be characterized by sampling the acoustic environment from hydrophone sensors (underwater microphones) attached to a variety of fixed and mobile instrument platforms. Analysis of this empirical data can then reveal how the soundscape varies over time, from place to place, and across the frequency spectrum. In addition, in recent years, there has been increased effort to conduct computer-based predictive soundscape modeling of anthropogenic contributions to soundscapes, based on the physical characteristics of the environment and the distribution and density of human activities.

Data Collection—Fixed Platforms

Fixed platforms include autonomous hydrophone instruments, which are typically battery-powered devices capable of recording sound for periods ranging from a few days to multiple years. A large variety of these devices have been developed by many different research groups and companies (see Sousa-Lima et al., 2013). Important features of these instruments include recording duration (which may be extendable via duty-cycling the recording), frequency response (sensitivity), sampling rate, depth limit, instrument self-noise, dynamic range, ease of deployment, and cost. Instruments may be deployed in a variety of manners (see Dudzinski et al., 2011). Most commonly the moorings are entirely beneath the ocean's surface which is usually quieter, and less prone to ship strikes and fishing gear interactions. Gaining wider use in recent years are moorings with a surface component allowing for access to solar power, and communication over line-of-sight radio, satellite, or cell phone networks (e.g., Cornell Laboratory of Ornithology 2013, Marine Instrumentation Ltd. 2013). Some systems include software for detection of events of interest, such as vocalizations of a certain species. These detections may be used either to turn on recording (e.g., Tregenza 1999) or for real-time transmission of detected signals to shore.

Another form of fixed sensor is the cabled hydrophone or hydrophone array. These systems have been built by academic, private, and military groups; they feature real-time sound streaming from one or more hydrophones at each site. The U.S. Navy, for example, has long operated the large-scale Sound Surveillance System (SOSUS), and since the early 1990s has made it available to researchers with a security clearance (Nishimura & Conlon 1994). More recently, a number of cabled systems have been, or are being, installed for scientific research off the coasts of the U.S., Canada, Japan, Australia, and Italy, often in conjunction with other sensors following the concept of ocean observatories (e.g., Isern & Clark, 2003). Also, private researchers have installed hydrophones short distances offshore in a number of places around the world.

Data Collection—Mobile Platforms

Mobile hydrophone platforms have long included vessel-deployed hydrophones, typically towed in an array behind the vessel or dangled overboard. These are still widely used for marine mammal surveys, by NOAA and many other researchers around the world. More recently, a variety of additional mobile platforms have come into use including hydrophone-equipped autonomous vehicles and drifting buoys. Autonomous vehicles include ocean gliders, which can use buoyancy changes and wings to "fly" forward through the ocean or wave energy to propel themselves forward , and propeller-driven vehicles, which travel faster than gliders but often have higher noise levels. Drifting buoys are untethered and drift freely with currents, may be either surface- or subsurface-deployed, and may be either expendable or recoverable. In addition, acoustic recording tags have been developed to be placed on individual animals as part of broader behavioral studies. These tags may record the animals' vocalizations and other sounds the animal may hear, simultaneous with other parameters such as acceleration, pitch, roll, and yaw. These animal-borne tags, while requiring careful ethical consideration in their use, can provide previously unobtainable data on animal responses to sound through 3-dimensional reconstructions of animal movement and behavior underwater, in the presence of natural and human sound sources.

Systems standardization and documentation

While the use of identical hardware systems is ideal for making comparative measurements, in the absence of this, *standardization and/or careful documentation of system characteristics are essential to make results of soundscape surveys comparable over time or geographic regions*. Beyond basic information on deployments such as location (latitude/longitude, sensor/water depth), sampling rate, and recording start and end times, thorough documentation on the equipment configuration should include information on the frequency response, sensitivity, and self-noise of the hydrophone and recording system, directivity of the hydrophone, temporal drift and/or calibration of the recording system, and configuration of the deployment system (especially any compensation to reduce vibration and strum) including sensor depth. Also important are environmental characteristics: water depth, vertical sound speed profile (or at least temperature profile), wind speed, wave height, and bottom characteristics if available.

Data Analysis

Acoustic data analyses can be carried out on with a wide variety of programs designed specifically for sound analyses. Both readily available, off-the-shelf programs and software (e.g., Ishmael, Avisoft, Raven, to name a few), as well as custom-written scripts in programming languages like MatLab or R, can perform a range of acoustic analyses on the recorded data to describe its features, including the spectral (frequency) and temporal composition, and received levels of sound in the datasets.

In the first instance, specific sound types of biological, abiotic, or anthropogenic origin can be extracted by browsing the data for the sounds of interest (Figure 3-2). These analyses can be conducted manually, by reviewing spectrograms visually and aurally, or by using automated detectors for specific signals. Calls of a species of interest (mammal, fish, snapping shrimp, etc.) may be extracted for studies of seasonal and spatial animal distributions, response to anthropogenic activities, behavior, acoustic repertoires, levels at which animals produce sound, and most recently, for population density and absolute abundance estimation using cutting edge techniques that are rapidly being developed (for a review see Marques et al., 2013). If data is sampled from multiple time-synchronized hydrophones, a sound source can often be localized and its movement tracked. With a known source location, either through acoustic localization or with another data source (e.g., Automatic Information System vessel tracking systems or known locations of human activity), the source level and frequency signature can be determined. *Determining accurate source features on a variety of human activities (e.g. seismic airguns, vessel traffic, pile driving) is an essential component in assessing potential impacts of sound on marine life and their acoustic habitats, and contributions to the broader oceanic soundscape.*

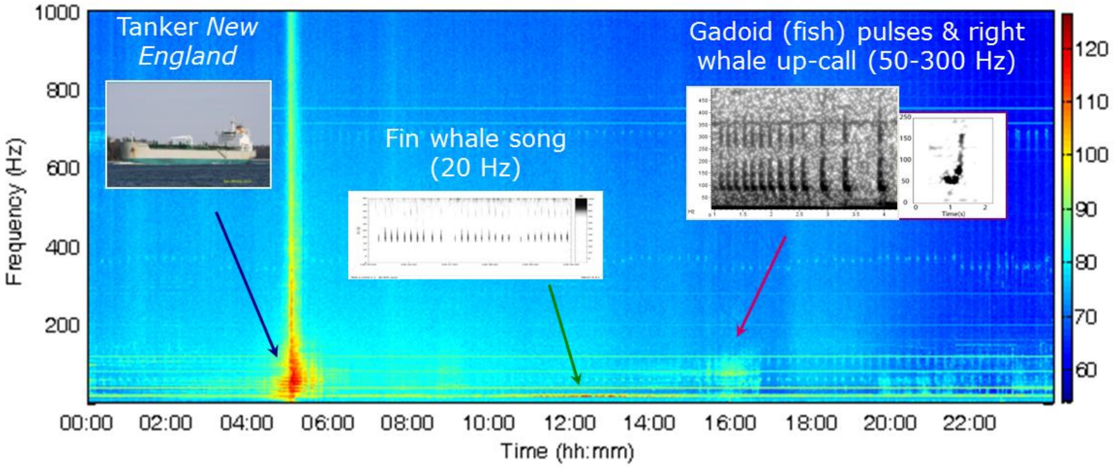


Figure 3-2. An example of a 24 hour soundscape with component noise sources illustrated. Recording is from a NOAA Northeast Fisheries Science Center and Stellwagen Bank National Marine Sanctuary collaboration with Cornell University.

When characterizing the soundscape of a place, it is often most valuable to look at longer time frames and the variability of the soundscape's characteristics over that time. The *temporal variation* of noise levels will describe changes in the sound pressure levels over time. The *spectral variation* of noise describes the variation in different frequency components present. And a combination of both domains describes the variability in both temporal and frequency components of the recorded soundscape. Figure 3-3 is an example of this type of analysis, illustrating how spectral content can be analyzed and displayed using a *noise level percentile distribution*, which, for each frequency band, shows the percentage of time that various noise levels are exceeded. For instance, the 90th-percentile value is a high sound level that is only exceeded 10% of the time. Such a percentile spectrum is useful when noise levels vary over time, as it can reveal very quiet periods or very loud events which, while being at significantly higher or lower levels than average, would only be present a very small percentage of the time. The noise level percentile spectrum is one of many ways (e.g., spectral probability density plots described in Merchant et al., 2013) to *quantify over long time frames the essential components of a soundscape of a place, illustrating variability in sound levels and frequency content of the soundscape.*

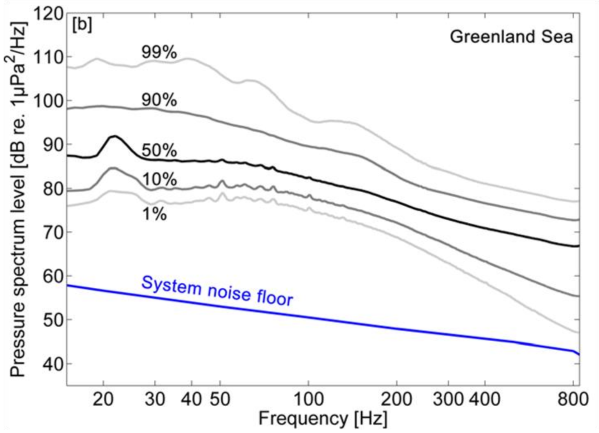


Figure 3-3. An example of a percentile noise spectrum. The 90th-percentile curve, for instance, is the level that is louder than ambient sound 90% of the time. Note the peak between 20-30Hz representing acoustic energy from fin whales. System noise floor represents the lowest levels that the instrumentation is capable of detecting. *Reproduced with permission from Klinck et al. (2012). Copyright 2012, Acoustical Society of America*.

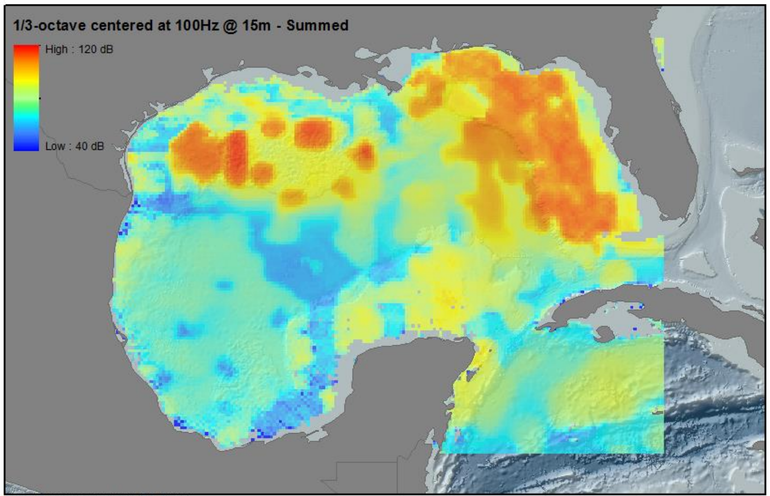
Soundscape data can also be displayed in ways that reveal broad-scale temporal information, and also allow exploration of how a soundscape changes over varying time-scales (e.g., seconds, daily, seasonal, annual). One such method is the long-term spectral average (LTSA), which is essentially a day- to years-long visualization (i.e., spectrogram) of sound over this time. While individual sounds from animals, human activity, or abiotic noise sources are not typically distinguishable within these long term averages, when there is a relative abundance in calling individuals or sound sources, their acoustic energy is clearly visible along with any seasonal patterns (Figure 3-1). On the other end of the scale, high temporal resolution (e.g. <1s) displays and analyses can also be conducted to characterize short-term changes, and assess potential impacts from intermittent, time-varying, or duty-cycled sources on biologically relevant time-scales.

Value of long-term baseline data

Well-characterized long-term acoustic records from the same location spanning a decade or more are rare. *These long-term acoustic datasets are essential for establishing baseline conditions, assessing long-term trends in characteristics of interest like noise levels or animal presence and eventually abundance, and determining the contribution of human activities to changing soundscapes*. Examples of long-term acoustic datasets include sounds recorded by NOAA PMEL from the U.S. Navy's SOSUS arrays (Fox & Hammond, 1994), and sounds recorded by the Comprehensive Test Ban Treaty Organization (CTBTO) for monitoring nuclear explosions worldwide (www.ctbto.org). Both of these systems sample only the very low frequency domain, which can be used for assessing the contributions of anthropogenic (container ships, seismic airguns) and many natural (baleen whales, storms, wave height, wind speed) sound sources to the ocean soundscape. Thus, these unique long-term archives of continuous passive acoustic data can permit analysis of both seasonal and multi-year variability in ambient sound levels at a multitude of temporal and spatial scales.

Predictive Sound Field Mapping

An alternative to gathering empirical measurements of ocean noise that has been increasing in prevalence in recent years, is conducting large scale computer-based predictive sound modeling (NOAA, 2012; SC/65B/Rep03rev, 2014). This technique is particularly useful for assessing the potential contributions of human activities to the ocean soundscape over large geographic scales, and based on varying amounts of human activities. *With the necessary components of the density and distribution of sound sources, their spectral characteristics and source levels, and environmental data (e.g., bathymetry, vertical sound speed profile of the water column, sediments), sound propagation modeling can be conducted that can predict the sound-field resulting from multiple sources at a variety of locations*. One example of this was the recent NOAA-led CetSound—SoundMap effort (http://cetsound.noaa.gov) which conducted predictive sound field modeling to provide annual average sound levels throughout most of the U.S. Exclusive Economic Zone resulting from a range of anthropogenic activities (e.g., global shipping, passenger, fishing vessel traffic, and seismic survey activity). This predictive modeling capability can also be used over shorter time frames and/or geographic scales to predict the sounds resulting from any individual or particular set of activities (Figure 3-4).



Marine Geospatial Ecology Lab, Duke University (2012)

Figure 3-4. Gulf of Mexico predicted average annual noise levels (1/3 octave band centered at 100Hz, at 15m depth) summing contributions from (a) large commercial shipping, (b) passenger vessels, (c) seismic surveys, and (d) rig support vessel traffic. *Note—this figure is for illustrative purposes only, and as with any modeling output, is directly reflective of the underlying input data. For example, the modeled seismic survey activity was based on effort in 2009, which may not be representative of survey activity during other time frames*.

CURRENT NOAA ASSETS/CAPABILITIES TO CHARACTERIZE AQUATIC SOUNDSCAPES

Passive acoustic monitoring and research at NOAA are being conducted by researchers at the NOAA Fisheries (NMFS) Science Centers (FSC), the National Ocean Service—National Marine Sanctuaries (NOS-NMS) and National Centers for Coastal Ocean Science (NCCOS), and the NOAA Office of Oceanic and Atmospheric Research— Pacific Marine Environmental Laboratory (OAR-PMEL) Acoustics Program. Most passive acoustic research projects at the NMFS FSCs and NOS NMSs focus on investigating seasonal presence, distribution, movement, and behavior of marine animals, as well as characterizing anthropogenic noise and assessing its potential impacts. The acoustics components of the PMEL Acoustics Program also focus on monitoring to detect and localize small submarine earthquakes and volcanic activities.

Acoustic Equipment

Currently, a variety of fixed and mobile platforms are being utilized by NOAA to record acoustic data to study the ecology and behavior of marine animals, ambient ocean noise, geophysical events, as well as anthropogenic noise that could affect marine life. The fixed platforms used by NMFS, NOS and OAR-PMEL include AURALs (Autonomous Underwater Recorders for Acoustic Listening), EARs (Ecological Acoustic Recorder), HARPs (High-frequency Acoustic Recording Package), MARUs (Marine Autonomous Recording Unit), C-PODs (Cetacean and Porpoise Detectors), AMARs (Autonomous Multichannel Acoustic Recorder), SM3Ms (Song Meter SM3M Submersible), PMEL produced Autonomous Underwater Hydrophones (AUH) and several regional hydrophone network nodes deployed in the Washington inland waters. For mobile platforms, the equipment used includes towed hydrophones and/or hydrophone arrays, sonobuoys, free floating hydrophones, dipping hydrophones, and gliders currently being used at six of the NMFS FSCs (see Table 3-1, Figure 3-5). Although most of these projects focus on recording signals of biological origin, acoustic data obtained during the process can additionally be used to characterize and improve our knowledge of underwater soundscapes.

Figure 3-5. OAR-PMEL AUH being deployed, and a towed array on the deck of a ship.

Table 3-1. Passive Acoustic Monitoring Capacity across NOAA offices (as of 08/2016)

NOAA Office	**Current Equipment Holdings (leased or owned)**	**Approx. Data Holdings**	**Staff Acoustics Capacity***	**Example Projects**
NMFS-AFSC	47 AURALs sonobuoys; towed array 3 EAR (lease) 14 CPOD 1 SM2M HF 1 DSG-Ocean 3 DSG-ST	Past : ~45TB Future: ~8TB/year	2 FTE ; 8 contractors;	ALTIMA (Arctic Long-Term Integrated Mooring Array); CHAOZ (Chukchi Sea Acoustics, Oceanography, and Zooplankton); CHAOZ-X (extension of CHAOZ); ARCWEST (Arctic Whale Ecology Study); High Arctic Passive Acoustics Study; CIBA (Cook Inlet Beluga Acoustics Project); Cook Inlet Anthropogenic Noise Study;
NMFS-NEFSC	37 MARUs 5 HARPs 6 Sound traps 2 Towed hydrophone arrays	Past: ~70TB FY16-17: >100 TB	2 FTE, 6 contractors, 3 short-term contractors/ interns/students.	Occurrence of fish, invertebrates, baleen whales & toothed whales in western N. Atlantic; Acoustic ecology of baleen whales; Soundscape comparisons among habitats; Acoustic abundance analyses of odontocetes
NMFS-NWFSC	17 EARS 3 CPODs 2 Towed arrays 96 Sonobuoys	Past: 28TB total Future: 4TB/year	2-FTEs	PODS (Pacific Orcinus Distribution Survey) Cruise Winter habitat of Southern Resident killer whales
NMFS-PIFSC	8 HARPs; multiple towed arrays; 9 miniHARPs	Past: ~130TB Future: collecting up to 20TB/yr	0.25 FTE, 3 contractors	Long-term monitoring across the central and western Pacific; acoustic monitoring of the Hawaii longline fishery; towed acoustics on abundance surveys
NMFS-SEFSC	3 HARPs 5 LARPs 3 towed arrays	Past: 100 TB Future: ~10 TB/year	½ FTE; 1 contractor	Right whale calving grounds project; Dry Tortugas sperm whale project

NMFS-SWFSC	19 DASBRs; 7 Towed Hydrophone Arrays (1 tetrahedral, 2 inline, 4 End Arrays); 6 CPODs and 1 DSG	Past: 36 TB Future: 30Tb	2 FTE permanent; 1 FTE term,	PASCAL- Passive Acoustic Survey of Cetacean Abundance Levels in 2016; CalCurCEAS 2014 survey; SOCAL-BRS Surveys; many sea trials to develop and test equipment
OAR-PMEL	North Pacific SOSUS hydrophone archive; 48 AUHs (autonomous hydrophones); 3 acoustics capable profile floats 2 acoustic sea gliders 1 slocum glider 1 Acousonde 3B	Past:19TB, Future: 0.5 TB/yr Past: 31 TB, Future: 5 TB/yr	1 FTE, 8 JI contractors	Long-term fin whale-ambient noise in N. Pacific Ocean Noise Reference Station Network, Equatorial Atlantic
NOS-NCCOS	2 Soundtraps (Oceaninstruments.co.nz, partnership with Duke University); 2 Remoras-Soundtraps packaged for gliders	Past: <100GB Future: 500 GB/year	1-FTE	Passive acoustic surveys for reef fish aggregations using ocean gliders; Soundscapes of temperate reefs; Fish and marine mammal responses to seismic surveys
NOS-NMS-Stellwagen	10 MARUs (through collaboration with NESFC and Cornell University) 2 Soundtraps	(included within NEFSC and NOAA-PMEL holdings)	1 FTE; 1 contractor (acoustic specialist); partial time from 1 FTE (GIS) & 1 contractor (GIS)	Occurrence and acoustic behavior of whales & fish in sanctuary; Sanctuary soundscapes; Vessel noise characterization; Sanctuary system noise monitoring (NRS collaboration)
NOS-NMS-Flower Garden Banks, Florida Keys and Gray's Reef	6 Soundtraps (through collaboration with NESFC)	Partial time from 4-6 FTEs (Conservation Science HQ staff & site Research Coordinators)	Partial time of 4-6 FTEs: Conservation Science HQ staff & site Research Coordinators	Sanctuary soundscapes

*Staff positions typically funded via a range of office programs in lieu of dedicated acoustics funds

Acronyms

AUH: OAR PMEL Autonomous Underwater Hydrophone
AURAL: Autonomous Underwater Recorders for Acoustic Listening
DASBR: Drifting Autonomous Spar Buoy Recorders
DSG: Loggerhead Ocean acoustic datalogger
EAR: Ecological Acoustic Recorder
HARP: High-frequency Acoustic Recording Package
LARP: Low-frequency Acoustic Recording Package
MARU: Marine Autonomous Recording Unit
NRS: Ocean Noise Reference Station Network
SM2M: Wildlife Acoustics Song Meter Submersible

Data Holdings—NOAA

Recording of passive acoustic data has been occurring throughout various NOAA offices at least sporadically for over 40 years. In the early 1990s, OAR-PMEL began archiving very low-frequency Navy SOSUS hydrophone array data, with more concentrated efforts utilizing their own capacity beginning later in the 1990s. In 2000, the AFSC set out its first long-term recorders in the SE Bering Sea to detect calls from endangered North Pacific Right Whales. Across NMFS, passive acoustic data collection ramped up between the early and mid-2000s (NMFS 2011). Currently, all the NMFS FSCs, many NOS NMS and NCCOS offices, and OAR-PMEL invest substantial efforts on passive acoustic research projects. Nearly all acoustic data being recorded currently are digitized (e.g., wav, mp3 formats), stored on hard drives, and therefore made accessible via a computer, although many recordings from early years (pre-2005) consist of either digital or analog data stored on magnetic media like DAT or HI-8 tape and retrieving these data can prove more challenging.

Due to the large sizes of digital acoustic files, data storage, archiving, and management at each facility and data sharing among NOAA research facilities is a challenging issue with estimates of over 100 TB per year of acoustic data accumulation for some FSCs. Passive acoustic data volume is continuing to grow across the agency. With such large raw data volumes being accumulated in various formats by offices throughout NOAA *a unified metadata and data archival capacity is sorely needed to support: proper documentation and long-term preservation of these data, as well as allowing for simplified querying and access to the data across NOAA.*

Data and metadata archival system pilot study (2014-16)

A pilot study between NEFSC, AFSC, and the National Centers for Environmental Information (NCEI) was recently implemented to develop archival system capacity for passive acoustics data. To begin, both AFSC and NEFSC have utilized Tethys, the metadata and spatial-temporal database developed by Dr. Marie Roch of San Diego State University for their own data holdings, and provided the data and metadata for NCEI to develop compatible data ingestion and management procedures. In parallel, IOOS, NMFS, and NCEI have been collaborating to develop an International Standards Organization (ISO) compliant metadata standard for passive acoustic datasets. Merging these projects, to provide a long term archival capacity, with ISO-compliant metadata is currently underway at NCEI and, if maintained, would be a great advance in NOAA's capacity to manage, utilize, and provide public access to passive acoustic data.

Monitoring Data Resulting from Permitted Activities

NMFS currently requires the collection of monitoring data in support of many of the activities it authorizes under numerous statutes (Chapter 1). These include 'sound source verification' (SSV) data, characterizing various source sound signatures arising from permitted activities (e.g., seismic airgun surveys, dynamic thrusters on vessels, pile driving), and also short- to long-term deployment of acoustic recorders associated with various projects. Thus for many years much of this information-rich data has been reported back to NOAA, but is not being accessed or utilized in any standardized fashion that would allow its value to be realized. *NOAA could* expand *its capability to more effectively utilize this data in adaptive management of permitted activities, as well as in broader scientific studies of species, special places, and anthropogenic activity impacts.*

TANGIBLE OUTCOMES APPLICABLE TO NOAA'S OCEAN NOISE STRATEGY MISSION

The highest priorities for increased NOAA capacity to monitor and characterize soundscapes will be in locations of significance for acoustically sensitive species (Chapter 1, Appendix A), designated habitats of importance (e.g., special places or sanctuaries as described in Chapter 2), or locations of significance undergoing rapid and large scale environmental or human use changes. With increased capacity, the following tangible benefits will be realized:

Quantification of Spatial, Spectral, and Temporal Variability of Ambient Noise Conditions

As noted earlier (Figures 3-1 to 3-3), ambient noise conditions naturally vary over time, among locations, and in the frequency composition of the sounds that comprise them. Quantifying soundscapes and their variability will improve understanding of the various ambient noise conditions animals naturally encounter, and the changing contributions of various sources of noise in the marine environment. This will provide context to understand how animals might cope with wide ranging noise conditions and the compensation mechanisms they may employ (e.g., Parks et al., 2007) and assess the impact of future activities that generate underwater sound.

Example: Contribution of geo-seismic activity to soundscapes— Global seafloor earthquake patterns show that ocean basin seismic activity tends to be narrowly focused along mid-ocean ridges and along subducting continental margins. Earthquakes at these locations typically have shallow origins and thus can couple efficiently into the water column and convert to acoustic energy. To illustrate this, during the past 20 years of seafloor seismic monitoring in the northeast Pacific Ocean, nearly 50,000 earthquakes were detected over a 1km x 105 km area of seafloor. Seismic energy can thus be a significant, albeit sporadic contribution to the naturally occurring low-frequency ocean soundscape.

Increased Understanding of Anthropogenic Sound Sources, Their Contributions to Soundscapes, and Changing Human Use Patterns

Human use of the marine environment is continuing to expand to more locations with greater intensity worldwide. An increased capacity to characterize soundscapes will allow NOAA to obtain a more detailed understanding and quantification of the characteristics of human noise sources and how they contribute to oceanic soundscapes. In addition, increased monitoring and predictive capacity will allow NOAA to assess how future changes in human use and activities may alter soundscapes in the future.

Example: *Climate change effects on soundscapes*—Climate change has altered the extent of sea ice coverage, sea temperatures, ocean acidity, and oceanographic currents, which is expected to lead to changes in species composition, abundance, and distribution at multiple trophic levels. These alterations to the natural environment will include a changing soundscape as the occurrence and distribution of biotic and abiotic sound sources will be modified. With current predictions now estimating that the Arctic could be ice-free in the summer within twenty years (Overland & Wang, 2013), the opening of new maritime transportation lanes, and expansion of oil and gas-related exploration and development and tourism into previously closed seasons and localities will likely result. This combination of increasing human activities, and changes in range distributions of marine animals, and in oceanographic and atmospheric dynamics, will lead to large-scale alterations of the Arctic soundscape.

Improving Understanding of Behavior and Biology of Marine Life

Much of NOAA's current passive acoustics research focuses on gathering information on the distribution, seasonal presence, and behavior of vocally active species, which are essential inputs to NMFS stock assessments. In recent years, increasing effort has led to advances in the use of passive acoustics to assess the relative abundance or density of vocal species (Marques et al., 2013). With further development and the addition of essential information on a species' vocal behavior and the variability in sound production among individuals (e.g., vocalization rate, demographics, seasonality) and local sound field characteristics (e.g., detection range, frequency-specific propagation conditions, ambient noise levels), these techniques should ultimately lead to a greater ability to use passive acoustics to refine absolute abundance estimates which can then feed directly into stock assessments.

Assessments of Effectiveness of Noise Mitigation Strategies

As attention to noise related impacts to marine life continues to increase, mitigation strategies are increasingly likely to be employed. These include measures like shifting of shipping lanes, vessel speed restrictions, and use of noise reduction technologies. A greater ability to characterize the soundscape will allow NOAA to assess the effectiveness of these measures by quantifying the resulting changes in surrounding soundscapes.

Increased Accuracy of Predictive Sound Field Modeling

With increasing use of predictive sound field mapping tools (NOAA, 2012; SC/65B/Rep03rev, 2014) there is a clear need to quantify the uncertainty in and verify accuracy of the predicted sound levels through comparison with empirical measurements. Empirical data are also essential to help characterize difficult-to-model environments (e.g., shallow coastal waters). In addition, as noted above, obtaining characterizations (source level, frequency composition, directivity) of specific anthropogenic sound sources is essential information to increase the accuracy of modeling efforts predicting sound fields resulting from human activities.

FUTURE DIRECTIONS

As NOAA begins to implement an agency-wide Ocean Noise Strategy, there are a range of actions that can be taken to work towards the goals of this strategy. Of perhaps the greatest importance, is the overarching need to coordinate activities among the various NOAA line offices and to prioritize the development of NOAA's assets in ways that can address priority research and management needs of species and habitats (Chapters 1 and 2). With a more coordinated approach to passive acoustic sampling, archiving of data and metadata in an accessible database, as well as of processing and analysis routines, NOAA will take great strides towards enhancing its capability to characterize, understand, and assess soundscapes and the variety of sounds that comprise them. The following actions, while not a comprehensive or exhaustive list, are concrete steps related to soundscape characterization that are particularly well suited to cross-agency coordination.

1. ***Establishment of NOAA-led, long-term, standardized passive acoustic research capacity across the agency—*** While many offices across NOAA carry out passive acoustic research programs, they do so largely independently of others, often-times raising their own external funds to support the work. Key science needs would be met and knowledge gaps filled if NOAA committed to maintaining a long-term baseline monitoring capability that is coordinated across offices and standardized to the maximum extent feasible. An example of this is t*he NOAA Ocean Noise Reference Station Network (NRS).* The NRS is a collaborative effort, begun in 2014,

between OAR's Pacific Marine Environmental Laboratory (PMEL), NMFS Science Centers and the Office of Science and Technology, NOS National Marine Sanctuary Offices and the National Park Service. The objective of the project is to establish an initial NOAA-operated network of eleven ocean noise reference stations in U.S. waters to monitor long-term changes and trends in the underwater soundscape and acoustic habitats. By deploying identical and calibrated autonomous acoustic recording systems (PMEL's Autonomous Underwater Hydrophone packages) at each reference station, NOAA is recording consistent and comparable multi-year acoustic data sets covering the major regions of U.S. waters. Instruments are deployed for a nominal period of two years and record continuously over the 10-2500Hz frequency range, before being recovered and redeployed. Ultimately, upon successful completion of the pilot study and demonstration of its value, this network will be expanded to more locations, sample over a greater frequency range, and be maintained over decades to come. Notably, a recently formed Interagency Task Force on Ocean Noise and Marine Life (ITF-ONML) of the Subcommittee on Ocean Science and Technology (SOST) has highlighted this need across federal agencies. The ITF-ONML is now working towards aligning agency interests in establishing a long-term passive acoustic monitoring network, including the NRS system as a core component.

2. ***Standardization of basic data analysis routines and output metrics***—Beyond establishing a standardized metadata format and centralized passive acoustic database, a set of basic analysis routines should be applied to all appropriate datasets. Depending on the objectives of the data analysis (e.g., characterizing variation in ambient noise conditions, detection of animal calls, etc.), acoustic parameters should be carefully defined and standardized, to the extent possible, often requiring a combination of several metrics. One example of this is the current European Union effort to achieve or maintain a good environmental status by 2020 (Marine Strategy Framework Directive, European Commission, 2008), which requires documenting and characterizing underwater noise in all EU marine regions to evaluate if there is no adverse effect of energy inputs on any component of the marine environment. Under this directive, two indicators of underwater sound have been developed (European Commission, 2010):
    a. Proportion of days and their temporal and spatial distribution per year over a grid in which low- and mid-frequency impulsive sounds (10 Hz – 10 kHz) exceed a specific threshold, measured in both Sound Exposure Level, SEL (dB re 1µPa^2·s) and peak level (dB re 1µPa$_{peak}$).
    b. Trends in the ambient noise level (in dB re 1 µPa RMS) within the 1/3 octave bands 63 and 125 Hz measured as 1 full year averages (arithmetic mean).

   A recent international soundscape mapping workshop worked to develop comprehensive recommendations (see workshop report SC/65B/Rep03rev, 2014) for soundscape analysis and characterization that were consistent with both the EU-MSFD recommendations and the predictive sound field mapping methodologies developed as part of NOAA's recent Cetacean and Sound Mapping effort (NOAA, 2012). Both of these efforts demonstrate the clear need for appropriate metrics to characterize and compare short and long term variability in noise across sites. Standardized analysis routines and metrics, developed in consultation with partners and stakeholders, and in consideration of national and international standards, will then allow for automated processing of datasets as well as detection of specific anthropogenic noise events, and occurrence of marine animals and/or abiotic events.

3. ***Archiving of passive acoustic meta and raw data***—Currently, while particular projects result from collaborations between different NOAA line offices (e.g., above NRS pilot study being initiated), each office that records passive acoustic data does so largely independently of others.

Data from such efforts are typically stored locally on hard drives and/or servers, and there is no current metadata standard that effectively describes the passive acoustic datasets from various platforms. A standardized metadata format (as described above) to accompany all NOAA passive acoustic datasets should be adopted across the agency. In addition, there is a strong need for a centralized data archival capability to improve access to and utility of current holdings, and sustainably preserve these data. Recognizing this need, the SOST's ITF-ONML (noted in recommendation 1) is similarly working to align federal agency interests in a centralized archive of passive acoustic data. This effort will likely build upon recent discussions with NOAA's National Centers for Environmental Information (NCEI) about providing this capability. A pilot study is being conducted between NMFS and NCEI to establish and test, with a small subset of data, the methodology for maintaining, archiving, and disseminating NMFS' existing and future passive acoustic data. With the successful demonstration of this capability, the effort should ultimately be expanded to include passive acoustic data sampled NOAA-wide, metadata describing the raw data, and the results of the standardized analysis routines.

4. ***Developing NOAA 'in-house' predictive sound field capacity*—**While NOAA led and coordinated the CetSound-SoundMap effort (http://cetsound.noaa.gov), the computationally intensive sound propagation modeling was carried out by external collaborators. Moving forward, NOAA needs to develop and establish an internal capability to conduct this sound field modeling for a variety of circumstances. This will provide the ability to: predict resulting sound-fields from (a) individual activities that are seeking authorization under various NOAA statutory authorities in order to assess potential species level impacts; (b) multiple human activities that are necessary in order to conduct place-based management of acoustic habitat; and (c) address NOAA's increasing need to more effectively assess cumulative impacts of human activities on species and habitats.

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NOAA Ocean Noise Strategy Implementation Case Studies

INTRODUCTION

Fulfilling NOAA's role as an ocean steward will require the agency to effectively manage a range of ocean noise effects. Chapters 1-3 of the NOAA Ocean Noise Strategy Roadmap present recommendations to guide the agency's management and science actions towards understanding and managing noise impacts to (1) protected, endangered and commercially managed species and (2) acoustic habitats for sound-sensitive and sound-producing marine life and (3) the development of enhanced NOAA capacity to characterize marine soundscapes of concern. Risk assessment provides a scientific framework for integrating information regarding the impacts of noise on high priority, acoustically sensitive and active marine animals and their habitats. As such, it is a decision support tool that aids effective management.

Risk assessment is part of an iterative process containing five components when used to make management decisions:

1) Formulate the problem
2) Assess risk
3) Evaluate potential management actions
4) Implement selected management actions
5) Monitor the effects of management actions

Problem formulation seeks to identify sources of risk, species that may be impacted, timing and location of impacts, and mandates for managing risk. Stakeholder participation in formulating the problem can increase the success of management actions.

Risk assessment requires spatially explicit characterizations of human activities, management jurisdictions, species distributions, methods for estimating the co-occurrence of these factors, metrics for estimating the consequences of co-occurrence, and explicit consideration of sources of uncertainty (Hope 2006). The framework for assessing risk from ocean noise described below synthesizes frameworks suggested in Ellison et al. (2012), Moore et al. (2012), Thompson et al. (2013) and Francis and Barber (2013). A spatially explicit characterization of the soundscape (Chapter 3) is required to assess the risk of ocean noise to marine species. Spatially explicit characterizations of species distributions may range from densities predicted by habitat models to formal critical or essential habitat to boundaries of biologically important areas based on expert opinion (Chapter 1, Appendix B). Places to be protected for their holistic value, including their acoustic quality, include marine protected areas such as National Parks and National Marine Sanctuaries (Chapter 2). The types of representations that are available to depict species distributions and soundscape variables, as well as the types of management jurisdictions that are available to support implementation of evaluated management options, will determine the methodologies that are applied to assess risk.

Soundscape and species distributions can be integrated to estimate co-occurrence using selected frequencies referencing presumed or known hearing sensitivity or audiogram weighting (Erbe et al., 2014) across a range of frequencies. To date, most attention has focused on short-term consequences of the co-occurrence between marine mammals and single, high-intensity noise sources. Dose-response relationships can be used to assess the likelihood of mortality and injury (including hearing loss) from loud noise (Ellison et al., 2012) or behavioral disruption from a single noise source (Moretti et al., 2014).

However, the effects of chronic noise, multiple noise sources, and the context in which noise is experienced (e.g., the activity state of an animal and the spatial relationship between the noise source and an animal; Ellison et al., 2012) must also be considered. Estimates of the loss of acoustic communication space can be a valuable tool for assessing risk caused by chronic noise (Hatch et al., 2012). Risk can be also be defined as the number of individuals estimated to be impacted by noise. Alternatively, areas of elevated risk may be identified where noise overlaps with high species densities (Erbe et al., 2014), biologically important areas or protected areas. Risk to populations can be derived by linking individual impacts to vital rates (Thompson et al., 2013).

Uncertainty occurs in each stage of risk assessment. Uncertainty caused by lack of knowledge can be addressed through further data collection and analysis, while uncertainty caused by stochastic variability cannot (Hope 2006). To correctly interpret the results of a risk assessment and use the results to evaluate potential management actions, all sources of uncertainty must be clearly identified. Documenting the assumptions used in the assessment and data availability and quality are powerful tools for identifying sources of uncertainty (Thompson et al., 2013). Sensitivity analysis can also be used to understand the relative importance of assumptions and data gaps. Explicitly identifying uncertainty helps managers understand the degree of confidence they can place in the risk assessment and helps to prioritize future data collection efforts (Hope 2006).

Risk assessments can be used to evaluate potential management actions, such as the removal or modification of a noise source (e.g., sonar or shipping lanes) or avoiding species habitat. Barlow and Gisiner (2006) provide a good discussion of the challenges in applying these management actions to activities that may impact beaked whales. When selected management actions are implemented, monitoring may be required, such as visual or acoustic surveys conducted prior to, during, and after specific events (e.g., use of military sonar or seismic exploration) or changes to a noise source. It is important to design these monitoring efforts to address identified data gaps as much as possible. The location and timing of activities, as well as potential long-term changes in noise associated with the activities (e.g., increases in shipping traffic resulting from vessels servicing offshore energy developments), should also be documented to improve soundscape characterizations and our understanding of acoustic habitat. The results of these efforts should be incorporated in the risk assessment to reduce uncertainty, update evaluations of potential management actions, and inform selection of future management actions.

Using the proposed risk assessment framework can assist NOAA in identifying areas that require noise management and the degree to which current (e.g., Marine Mammal Protection Act, Endangered Species Act and National Marine Sanctuaries Act) and latent (e.g., Magnuson Stevens Act) tools are sufficient to achieve successful noise impact management. It can also assist NOAA in identifying data gaps and prioritizing the allocation of resources to address those gaps. Application of the risk assessment framework is explored here in two case studies. The locations of these studies were chosen to showcase the application of methodologies discussed in the Roadmap in differing contexts (e.g., types of information available and relevant NOAA mandates for addressing noise impacts).

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Case Study 1:
Assessing the Risk of Chronic Shipping Noise to Baleen Whales off Southern California[7]

Introduction

Ocean noise produced by human activities has significantly increased since the beginning of the industrial era, although the changes have not been evenly distFributed in space and time. Analyses of data collected between 2004 and 2012 at two locations that are not located near major shipping lanes (one in the equatorial Pacific Ocean and one in the South Atlantic Ocean) showed decreases in the ambient sound floor and other sound level parameters (Miksis-Olds & Nichols 2016). In contrast, low-frequency noise has increased in the Northeast Pacific Ocean since the 1960's (Andrew et al. 2011, Chapman & Price 2011) and in the Indian Ocean over the last decade (Miksis-Olds et al. 2013). The increase in low-frequency noise observed in both locations has been linked to increases in shipping. Frisk (2012) used the Northeast Pacific Ocean data that spans several decades and data from areas in the South Pacific Ocean with extremely low shipping traffic to provide a theoretical explanation for the increases. In particular, they show that the increase can be attributed primarily to commercial shipping and that shipping is linked to the global economy.

The Northeast Pacific Ocean data has also been used to assess spatial and temporal variability in noise. In particular, long-term changes (30-50 years) in low-frequency noise have been observed at several locations off the coast of California (Figure 4-1). At two sites, one off Point Sur and one off San Nicolas Island, that occur in deeper waters beyond the continental margin, noise increased at approximately 3dB re 1µPa per decade in the 30-50 Hertz (Hz) band (Andrew et al. 2002, McDonald et al. 2006). This increase is likely representative of noise increases in the Northeast Pacific Ocean deep sound channel caused by increasing commercial shipping, including both increases in the number of ships and increases in their gross tonnage and horsepower (McDonald et al. 2006). Although the change in noise at these two sites was similar, the 4-8dB higher noise levels at Point Sur than at San Nicolas Island are likely caused by the closer proximity of the Point Sur site to major shipping lanes. In contrast, noise measured during periods with no local ship traffic did not change between the 1960's and the 2000's at a site on the continental shelf (in waters 110m deep) near San Clemente Island, suggesting that noise at this site is influenced more by wind, biological sources, and local shipping than distant shipping noise from the deep sound channel (McDonald et al. 2008). More recent measurements of noise (i.e., 1994-2007) at Point Sur and San Nicolas Island show that low-frequency noise is remaining constant or slightly increasing, with one exception of decreasing 50Hz noise at Point Sur (Andrew et al. 2011).

The noise monitoring locations in the Northeast Pacific Ocean overlap with important habitat for baleen whales. In particular, blue whales feed in southern California waters from June to October (Calambokidis et al. 2015), humpback whales feed in these waters from March to November (Calambokidis et al. 2015), and aggregations of fin whales have been observed in these waters year-round (Forney et al. 1995). A seven year summary of blue and fin whale calls in southern California waters detected blue whale 'B calls' (tonal calls with a downsweep in frequency) between June and January, with a peak in September (Sirović et al. 2015). The 'B calls' are one of three blue whale calls that have been recorded in the southern California Bight (Sirović et al. 2015). Series of 'A calls' (a series of rapid, low-frequency pulses) and 'B calls' (~16Hz) are believed to serve a reproductive function (Oleson et al. 2007). Blue whale 'D calls' are more variable in their characteristics (~25-90Hz) and are

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[7] A version of this work is under review for publication as Redfern, J., Hatch, L.T., Caldow, C., DeAngelis, M.L., Gedamke, J., Hastings, S., Henderson, L., McKenna, M.F., Moore, T.J., and Porter, M.B. *Endangered Species Research.*

believed to serve a social function (Oleson et al. 2007). Fin whale 20Hz calls (these downswept pulses can be produced in regular or irregular sequences, with regular sequences attributed to males) were detected year-round, but occur at the highest levels between September and December, with a peak in November (Sirović et al. 2015). Humpback whale calls (~150-1800Hz) have also been recorded in these waters (Helble et al. 2013).

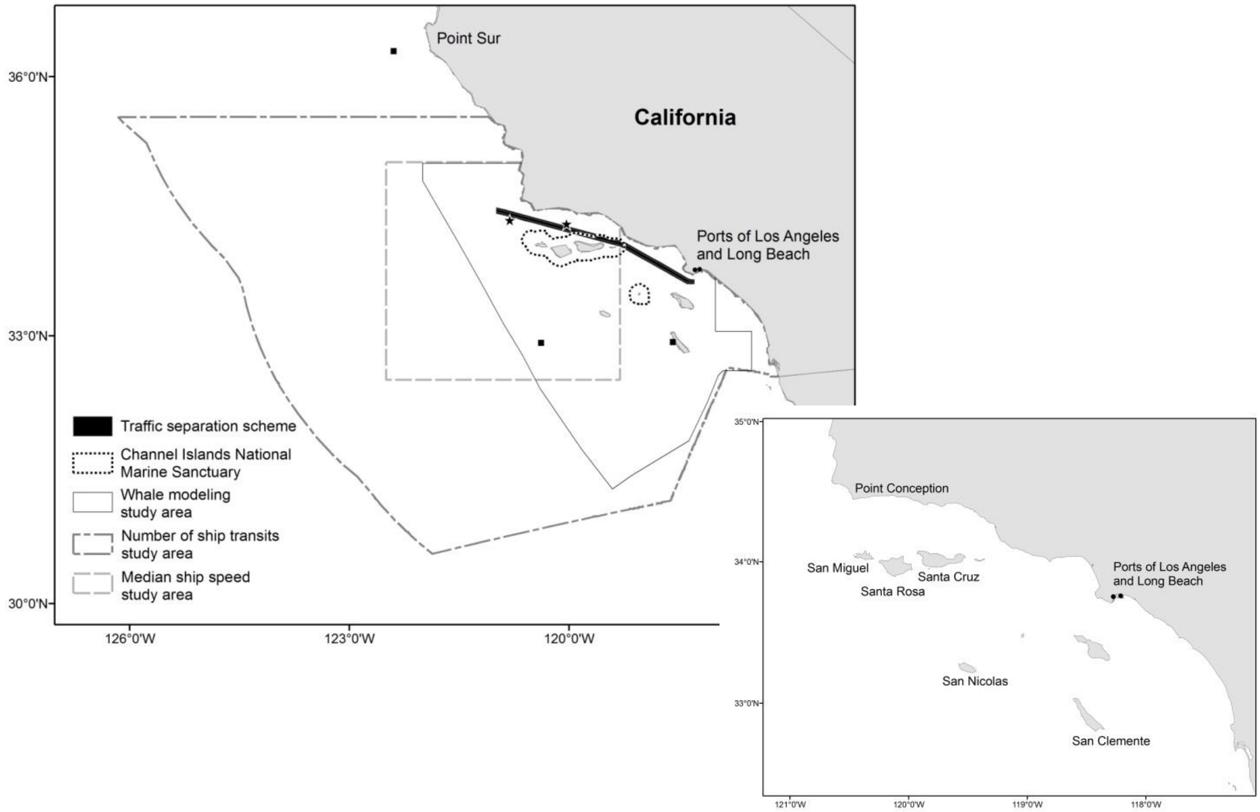

Figure 4-1. Waters off the southwestern United States are shown, including the Channel Islands National Marine Sanctuary, the Traffic Separation Scheme in the Santa Barbara Channel adopted by the International Maritime Organization, and three study areas used in our analyses: the whale modeling, number of ship transits, and median ship speed (see text for details). The two largest ports (Los Angeles and Long Beach) are shown as black circles. The locations of High-frequency Acoustic Recording Packages are shown as black stars and locations associated with historic noise monitoring referenced in this study (i.e., off Point Sur, west of San Nicolas Island, and off San Clemente Island) are shown as black squares. The inset shows the names of locations mentioned in the text.

All three species are currently listed as Endangered under the Endangered Species Act (ESA 1973) and as Depleted and Strategic under the Marine Mammal Protection Act (MMPA 1972). Although populations of fin and humpback whales along the California coast have been increasing since at least 1991 (Calambokidis & Barlow 2004, Moore & Barlow 2011) and Monnahan et al. (2014) suggest that blue whales may have reached carrying capacity, these species still face threats from ship strikes, entanglements, and anthropogenic noise. Although poorly understood, use of sound by baleen whales is assumed to include, but not be limited to, hearing conspecific calls. In particular, baleen whales are believed to rely on low-frequency sounds for feeding, breeding, and navigation. The potential effects of noise on baleen whales have been recognized for over 40 years (Payne & Webb 1971) and more recently behavioral responses to shipping noise have been documented for all three species (e.g., Sousa-Lima & Clark 2008, Castellote et al. 2012, Melcón et al. 2012). Low-frequency noise can also result in acoustic masking, which impedes an individual's ability to effectively perceive, recognize, or decode sounds of interest (Clark et al. 2009); consequently, areas with elevated noise may represent degraded acoustic environments. The large noise increases in the Northeast Pacific Ocean have occurred within the lifetime of these baleen whales and at frequencies that form an important part of their acoustic environment.

Southern California waters were among the first areas identified in national and international discussions of management techniques to reduce chronic underwater noise impacts because the Ports of Los Angeles and Long Beach (Figure 4-1) are ranked among the nation's largest for both the number of port calls and cargo capacity (MARAD 2014). The Channel Islands National Marine Sanctuary (CINMS) is located within these waters (Fig. 4-1) and has been a particular focus of these discussions because U.S. National Marine Sanctuaries have unique mandates associated with managing designated areas of the marine environment. For example, CINMS regulations prohibit taking (e.g., harassing, harming, capturing, or killing) any marine mammal within the Sanctuary, except as authorized by the MMPA and the ESA. An evaluation of noise impacts in the CINMS was completed in partnership with the Office of National Marine Sanctuaries (Polefka 2004) and was followed by a formal presentation of CINMS as a policy case study to examine methods for reducing shipping noise impacts (Haren 2007). Haren (2007) concluded that pursuit of sanctuary authority to regulate noise would face obstacles and would not address the influence of shipping noise beyond the boundary of the CINMS. Haren (2007) also noted that it is possible for the U.S. to request that the International Maritime Organization (IMO) designate the CINMS and surrounding areas as a Particularly Sensitive Sea Area (PSSA). A PSSA is an area that needs special protection because of its significance and vulnerability to shipping. Management measures associated with the PSSA could require or recommend that ships operate in a manner that reduces noise (e.g., travel at slower speeds or use alternative shipping routes). A better understanding of the risk of noise to marine species in this region is needed to define specific management measures (e.g., seasonal or dynamic slow speed zones and alternative shipping routes).

Estimates of the loss of acoustic communication space can be a valuable tool for assessing risk caused by low-frequency, chronic noise (Clark et al. 2009, Hatch et al. 2012). Spatially explicit risk assessments have also been conducted using spatial representations species of habitats and underwater noise generated by human activity. For example, Erbe et al. (2012) mapped cumulative underwater acoustic energy from shipping using a simple sound transmission model and Automatic Identification System (AIS) data. Erbe et al. (2014) combined these data with species distributions using audiogram weighting across a range of frequencies to identify species-specific hotspots of ship noise. Williams et al. (2015) used the same data and a similar approach to identify important species habitats that occur in areas with little noise.

We conducted a spatially explicit assessment of the risk of noise from commercial shipping to blue, fin, and humpback whale habitats in Southern California waters. We use AIS data to model noise at two frequencies that are part of the acoustic environment for these species and capture the variable contributions from shipping to noise. In particular, we selected 50Hz to represent a peak in the contribution from shipping to noise and 100Hz to represent where contributions from shipping to noise begin to diminish (National Research Council 2003). Predicted noise was compared to noise measurements at two sites within the study area.

Our analyses focus on the contribution of shipping to noise in baleen whale habitats, rather than focusing on masking of specific communication signals (e.g., the techniques that Clark et al. (2009) and Hatch et al. (2012) used). We assume that these species are using low frequencies for a variety of biological functions (feeding, breeding, and navigation) and that they can be broadly impacted by noise occurring at low frequencies. Our analyses identify areas where species habitat (defined using three sources of distribution data that capture different habitat elements) overlaps with low-frequency noise created by commercial shipping. Due to their extreme low-frequency calling activity, we assess risk, or potential for degradation of the acoustic environment, for fin and blue whales using our lower, 50Hz modeled noise. Our slightly higher 100Hz modeled noise is used to assess risk to humpback whales because it better reflects frequencies used in their vocal repertoires. These noise and risk characterizations allow managers and stakeholders to identify areas where chronic noise may impact the acoustic environment of these three species in Southern California waters. Specifically, our assessment identifies hotspots of noise in species habitats, similar to Erbe et al. (2014), and areas within species habitats that are currently quiet, similar to Williams et al. (2015).

Methods

Characterization of noise from commercial shipping

The noise modeling approach that we used is described in Porter and Henderson (2013) and is briefly reviewed here. This approach was used in the NOAA Fisheries CetSound project (http://cetsound.noaa.gov), but our models use higher resolution shipping information obtained from AIS data (see below). Noise modeling requires environmental information, such as bathymetry, bottom type, and sound speed. These data are used to calculate transmission loss for noise sources distributed on a grid of the study area. Noise level is then calculated by convolving the transmission loss with source level densities estimated for specific activities (e.g., shipping, pile driving, or sonar). This two stage approach provides a mechanism for quickly updating noise predictions to reflect changes in source level densities. Our models currently only include noise produced by commercial shipping; however, this approach could be used to integrate noise from multiple human activities.

Our models used depth from the SRTM30_PLUS data set (http://topex.ucsd.edu/WWW_html/srtm30_plus.html; Smith & Sandwell 1997, Becker et al. 2009). The seafloor bottom was categorized using sediment thickness (http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html; Divins 2003) and seabed properties from Pacific States Marine Fisheries Commission (http://marinehabitat.psmfc.org/physical-habitat.html). These data sources only differentiate between “hard” and “soft” bottom types. We used Bottom Sediment Type (Anonymous 2003) to define hard as cobbles to very coarse pebbles (phi = -6) and soft as fine silt (phi = 7.9). Basalt lies below the depth of the sediments as given by the NOAA sediment-thickness database. Sound speed was calculated by averaging “Summer” and “Fall” temperature and salinity climatologies from the World Ocean Atlas (Levitus et al. 2013). Finally, the scattering loss of sound due to sea surface roughness was incorporated in the models using significant wave height for a 10-knot wind speed (e.g., H. Zhang at ftp://eclipse.ncdc.noaa.gov/pub/seawinds/SI/uv/monthly/ieee).

The source level densities used in our models were obtained from measurements of shipping traffic. Specifically, we used AIS data collected between August and November in 2009 to calculate the number of ship transits in approximately 1km x 1km grid cells. The low-frequency noise produced by ships has the potential to propagate long distances. Consequently, the number of ship transits was calculated in an area that extended farther north and offshore than the whale modeling study area (Fig. 4-1). The whale modeling study area corresponds to the extent of transects covered by NOAA Fisheries’ Southwest Fisheries Science Center on systematic marine mammal and ecosystem assessment surveys. A broader area was used to analyze the shipping data to ensure that the models included noise from as many ships affecting the whale modeling study area as possible. AIS data were downloaded from NOAA Fisheries’ Coastal Services Center’s Marine Cadastre website (www.marinecadastre.gov).

We only used AIS data that had valid Maritime Mobile Service Identity (MMSI) values (201000000 and 775999999), speed over ground > 0 knots, and a navigational status of under way using engine, restricted maneuverability, under-way sailing, or undefined. The AIS data points were joined in chronological order to form a line if both points had the same MMSI and the elapsed time between points was less than one hour. If the elapsed time was greater than one hour and less than six hours, points that had less than a 30° change in heading were joined. If two successive points failed to meet these criteria, the current line ended and another was started. The total number of transits in each grid cell was calculated using the Line Statistics Tool in ArcGIS (Environmental Systems Research Institute 2014. ArcGIS Desktop: Release 10.2.2. Redlands, CA) for four length-based ship categories: 1) ≥ 18m and ≤ 120m; 2) > 120m and ≤ 200m; 3) > 200m and ≤ 320m and 4) > 320m. A search radius of approximately 0.5642km was used in the calculations because the area of the resulting circle is the same as the area of the grid cells.

The number of ship transits per cell was converted to source level densities using the source levels in Carey and Evans (2011) for the four length-based ship categories. The source levels in Carey and Evans (2011) are based on a worldwide shipping noise model known as the Ambient Noise Directionality Estimation System (ANDES), which references vessels active during the 1970s and 1980s. As reported in Carey and Evans (2011), source levels vary from 130dB for the smallest length category ("small tanker", 18-120m) and highest frequency (400Hz) to 180dB for the largest length category ("super tanker", >320m) and lowest frequency (50Hz). Ships in all four categories were modeled using a propeller depth of 6m. The source level densities (dB re 1µPa^2 / Hz at 1 meter) are reported by frequency in 1-Hz bands.

Noise levels produced by ships are influenced by ship size and speed (McKenna et al. 2013). We modeled noise associated with four ship-length categories that provide estimates appropriate for large-scale and long-term noise predictions. However, variability among individual ships within a length category was not incorporated in the noise model. The average speed for each length category was estimated to determine within-cell residency times for each transit and the associated accumulation of source levels. We obtained ship speeds from point-based AIS data collected by the U.S. Coast Guard between August and November in 2009 (accurate speed data cannot be obtained from the 2009 Marine Cadastre data). Specifically, we calculated the median speed for all ships in each length category within the bounding box shown in Figure 4-1. We limited our analyses to this smaller box, rather than using all shipping data, to avoid ships traveling into and out of the main ports because ships speeds close to ports are slower and do not represent speeds throughout the broader area. Although reduced noise has been measured for some ships when traveling at slower speeds (McKenna et al. 2013), the noise reduction may be offset by the increased time ships spend in an area when traveling at slower speeds. The median speed used to model noise was 6.40 knots for ships ≥ 18m and ≤ 120m, 13.50 knots for ships > 120m and ≤ 200m, 17.20 knots for ships > 200m and ≤ 320m, and 21.00 knots for ships > 320m.

The KRAKEN Normal Modes model (Porter & Reiss 1984, Porter & Reiss 1985) was used to model the transmission loss. Normal modes of the ocean are calculated at the center of each grid cell and the sound field is calculated along a fan of radials around the center of each grid cell using adiabatic mode theory (Kuperman et al. 1991). Resulting source level densities were convolved with transmission loss to estimate noise levels (dB re 1µPa^2 / Hz) for each cell at a discrete depth (30m) for two specific 1Hz frequency bands (50 and 100Hz). Predicted levels are expressed as equivalent, unweighted sound pressure levels (Lzeq), which are time-averaged across a specified duration, in this case the 122 days for August through November.

Predictions from the noise models were compared to empirical underwater acoustic data collected at two sites in the region (McKenna 2011), one north of the Santa Barbara Channel Traffic Separation Scheme (TSS) between Santa Rosa and Santa Cruz Islands and one on the southwestern edge of the TSS (Fig. 4-1). Acoustic data were collected using High-frequency Acoustic Recording Packages (HARPs) developed at Scripps Institution of Oceanography (Wiggins & Hildebrand 2007). The HARP hydrophones were deployed approximately 10m above the seafloor. Acoustic data collected in November 2009 were decimated to a sampling frequency of 2kHz and processed to calculate monthly sound spectrum averages. Spectrum measurements (reported as root-mean-square re: 1 μPa^2 /Hz) were produced using 225s samples of continuous data with no overlap between each spectral average using a discrete-time Fast-Fourier Transforms (FFT). All spectra were processed with a Hanning window and 2000 point FFT length, yielding 1Hz frequency bins. We calculated the arithmetic mean of the resulting pressure squared values and converted to dB scale for each frequency bin to be consistent with the modeling methodology. Monthly sound spectrum averages for 49 and 99 Hz (offset by 1Hz to avoid instrument system noise) were reported to represent empirical measurements of background noise that could be directly compared to 50 and 100 Hz noise level predictions. Comparisons were made between the empirical measurements from the HARP and predicted noise in the cell containing the HARP (see Table 1).

Modeled noise was also compared to pre-industrial noise levels, which are considered to represent little to no shipping traffic. McDonald et al. (2008) estimated that pre-industrial noise levels were 55dB at 40Hz at a site near San Clemente Island (Fig. 4-1). Wenz (1962) more generally represented "light shipping" conditions to be approximately 65dB at 50Hz. Drawing from this literature, we selected 65dB to approximate an upper bound for both 50 and 100Hz pre-industrial noise conditions in our study area. Modeled noise was summarized using the 10th, 50th (median), and 90th percentiles of predicted values. The estimate of pre-industrial noise conditions and the percentiles were used to define five categories for the predicted noise levels at 50 and 100Hz: <65dB (pre-industrial noise conditions), 65dB to the 10th percentile, 10th to 50th percentiles, 50th to 90th percentiles, and >90th percentile. These five categories were compared to time series of noise measurements off Point Sur (Fig. 4-1) to assess their correspondence to different volumes of shipping traffic.

Co-occurrence of whale habitat and noise

Whale distribution data were available from three sources that capture different elements of whale habitat. Redfern et al. (2013) developed habitat models for blue, fin, and humpback whales in waters off southern California using seven years of data (1991, 1993, 1996, 2001, 2005, 2008, and 2009) collected by NOAA Fisheries' Southwest Fisheries Science Center on systematic marine mammal and ecosystem assessment surveys. These surveys were conducted throughout the U.S. EEZ from August to November; consequently, model predictions of species density (Fig. 4-2) capture large-scale and long-term patterns in species distributions during a single season, but do not capture fine-scale patterns, particularly near the coast, or seasonality.

Calambokidis et al. (2015) developed boundaries for Biologically Important Areas (BIAs) in these waters (Fig. 4-2). The BIA boundaries were based on expert judgment and were drawn to encompass concentrations of feeding animals (direct observation of feeding or surfacing patterns suggestive of feeding) that were present in multiple years. Non-systematic, coastal (i.e., within 50nmi) surveys conducted by small boat to maximize encounters with blue and humpback whales for photo-identification and tagging studies were the primary data sources used to delineate the BIA boundaries. The BIAs for both species compare favorably to densities predicted by habitat models developed using data from the entire U.S. West Coast, including the southern California data used by Redfern et al.

(2013). Differences occur because the two data sets provide complementary information: the small boat surveys used to delineate the BIAs were better able to capture nearshore, fine-scale distribution patterns and the habitat models based on the systematic surveys captured broad-scale distribution patterns throughout nearshore and offshore waters (Calambokidis et al. 2015). We compare the BIAs to the densities predicted by Redfern et al. (2013) using whale habitat models developed for just southern California waters. Finally, the CINMS has been collecting opportunistic sightings (primarily from whale watching vessels) in the Santa Barbara Channel since 1999 (Fig. 4-2). These data provide information about where whales were present, but do not provide information about relative densities or absences.

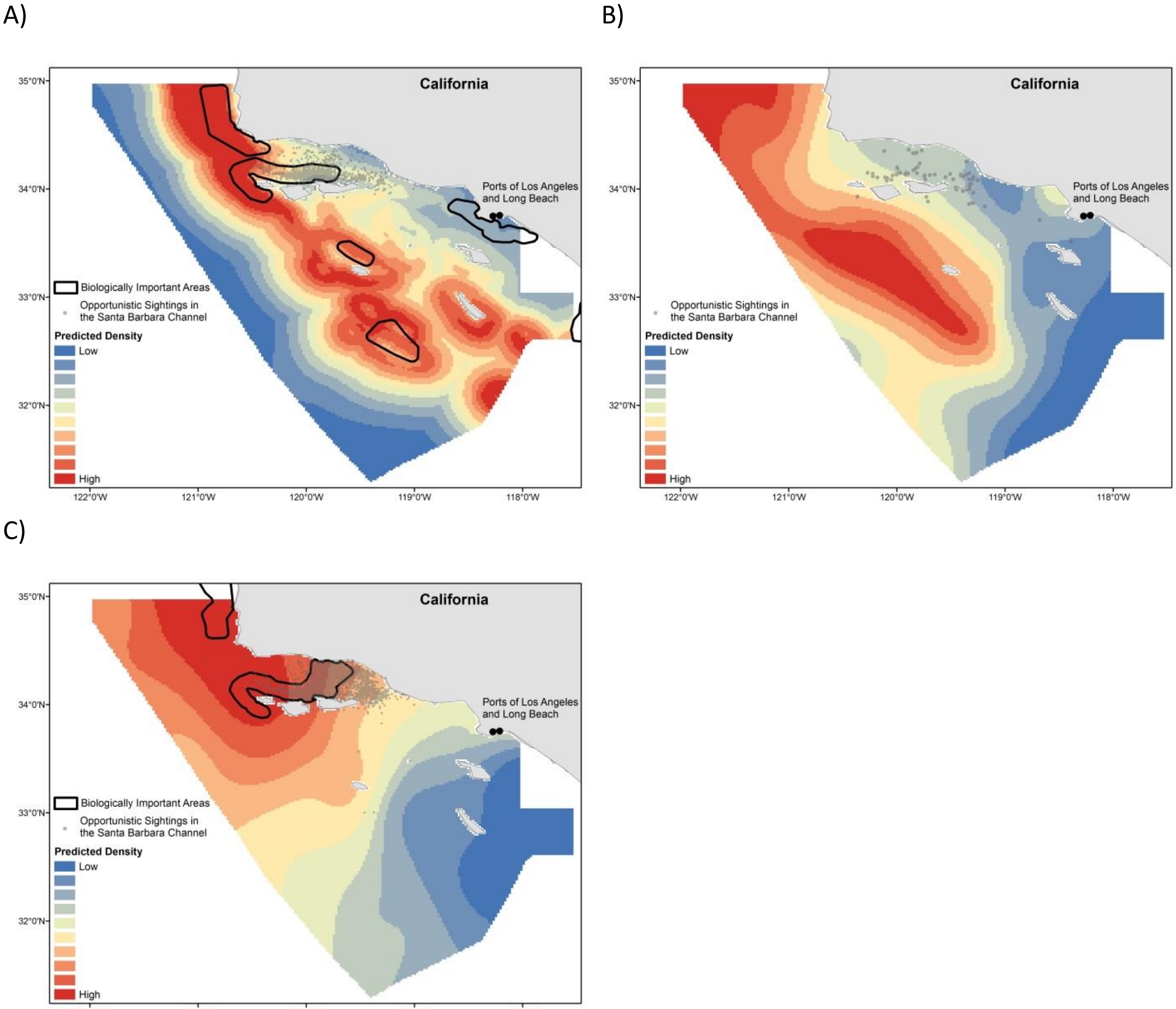

Figure 4-2. Habitat representations for A) blue, B) fin, and C) humpback whales between August and November from three data sources. A habitat model was developed from seven years of line-transect data and used to predict density throughout the whale modeling study area. Predicted densities are shown in 10 approximately equal area categories. Biologically Important Areas (BIAs) represent areas of high concentrations of feeding animals (BIAs have not yet been defined for fin whales). Opportunistic sightings have also been collected in the Santa Barbara Channel (the size of the dots is larger for fin whales, than blue and humpback whales, because there were so few fin whale sightings in the Channel).

We used all three sources of whale distribution data to estimate the co-occurrence of each species' habitat with noise. We assess risk, or potential for degradation of the acoustic environment, for fin and blue whales using the modeled 50Hz noise. We use the modeled 100Hz noise to assess risk for humpback whales because humpback whale vocalizations occur at higher frequencies than blue and fin whale vocalizations. Predictions from the habitat models were made in a 2km x 2km grid; they were extracted at the center of each 1km x 1km cell in the noise grid. Cells in the noise grid with one or more opportunistic sightings were categorized as a presence and other cells were treated as missing data. We calculated the number of cells within the five noise categories for the highest 20% of predicted densities, BIAs, and presence cells.

Results

Characterization of noise from commercial shipping

The 1km x 1km grid summarizing the number of ship transits between August and November 2009 shows that ships travelled in a broad area south of the northern Channels Islands and in the TSS within the Santa Barbara Channel (Fig. 4-3A and B). It also shows that smaller ships travel closer to the coast than larger ships. Predicted 50 and 100Hz noise levels at 30m depth reflected these shipping traffic patterns (Fig. 4-3C and D). However, predicted noise also reflects longer-distance, low-frequency propagation from distant shipping traffic in some regions, such as offshore of Point Conception, west of San Miguel Island, and south of the northern Channel Islands. In contrast, the Santa Barbara Channel is not exposed to noise from distant shipping traffic. Median predicted noise levels were 88dB at 50Hz and 77dB at 100Hz (Fig. 4-4). At the HARP north of the Santa Barbara Channel TSS between Santa Rosa and Santa Cruz Islands, predicted 50 and 100Hz noise levels were between 5-12dB higher than measured noise (Table 4-1). At the HARP on the southwestern edge of the TSS, predicted 50 and 100Hz noise levels were closer to measured noise (within 3dB) (Table 4-1).

Predicted 50 and 100Hz noise levels at the 10th, 50th (median), and 90th percentiles corresponded to low, moderate, and heavy levels of shipping traffic in a time series of measurements made off Point Sur (Table 4-2). The estimate of pre-industrial noise conditions (65dB at both frequencies) and the percentiles were used to define ranges of predicted noise levels associated with five volumes of shipping traffic: pre-industrial, low, moderate, heavy, and extreme (Table 4-2). Over 99% and 94% of the whale modeling study area contained predicted 50 and 100Hz noise levels, respectively, above pre-industrial noise conditions.

Noise levels predicted in the CINMS spanned the range of noise levels predicted in the whale modeling study area. When considering the entire CINMS and comparing it to predicted noise levels in the whale modeling study area, the CINMS represents a quieter area (Table 4-3). It contained some of the few remaining places within the whale modeling study area that are predicted to have pre-industrial noise conditions. Although the portion of the CINMS with pre-industrial noise levels was small at 50Hz (4%), approximately half of the CINMS was associated with 50 and 100Hz noise levels categorized as either pre-industrial or lower traffic volumes. However, approximately 22-24% of the CINMS also contained predicted noise levels in or above levels associated with heavy volumes of shipping traffic.

Table 4-1. Comparison of predicted 50 and 100Hz noise levels (August to November 2009) to noise measured at two HARPS in November 2009.

Location	Sea floor depth	Noise predicted at the HARP (dB)	Noise measured at the HARP (dB)
50Hz			
North of the TSS* between Santa Rosa and Santa Cruz Islands	578	91	80
Southwestern edge of the TSS	777	89	86
100Hz			
North of the TSS between Santa Rosa and Santa Cruz Islands	578	80	75
Southwestern edge of the TSS	777	75	78

* TSS = the traffic separation scheme adopted by the International Maritime Organization in the Santa Barbara Channel

Table 4-2. Ranges of predicted 50 and 100Hz noise levels (reported in decibels) associated with different volumes of shipping traffic. The upper values in the ranges for low, moderate, and heavy shipping traffic are the 10th, 50th (median), and 90th percentiles of predicted noise levels in the whale modeling study area (rounded to the nearest whole number). The noise levels for each percentile correspond to empirical measurements of different volumes of shipping traffic.

Volume of shipping traffic	50Hz	100Hz	Empirical measurement
Pre-industrial	< 65	< 65	Wenz (1962) “light traffic deep”; McDonald et al. (2008)
Low	65 - 81	65 - 68	Wenz (1962) “usual traffic deep”; Point Sur ~1960
Moderate	81 - 88	68 - 77	Urick (1984) "moderate traffic"; Point Sur ~1980
Heavy	88 - 96	77 - 85	Urick (1984) "heavy traffic”; Point Sur ~1995
Extreme	> 96	> 85	

Table 4-3. The percentage of the Channel Islands National Marine Sanctuary that contained predicted 50Hz and 100Hz noise levels associated with different volumes of shipping traffic (see Table 4-2 for the range of noise levels in each category).

	Channel Islands National Marine Sanctuary	
Volume of shipping traffic	50Hz	100Hz
Pre-industrial	3.9	42.9
Low	49.7	12.8
Moderate	22.3	22.4
Heavy	13.2	14.3
Extreme	10.9	7.6

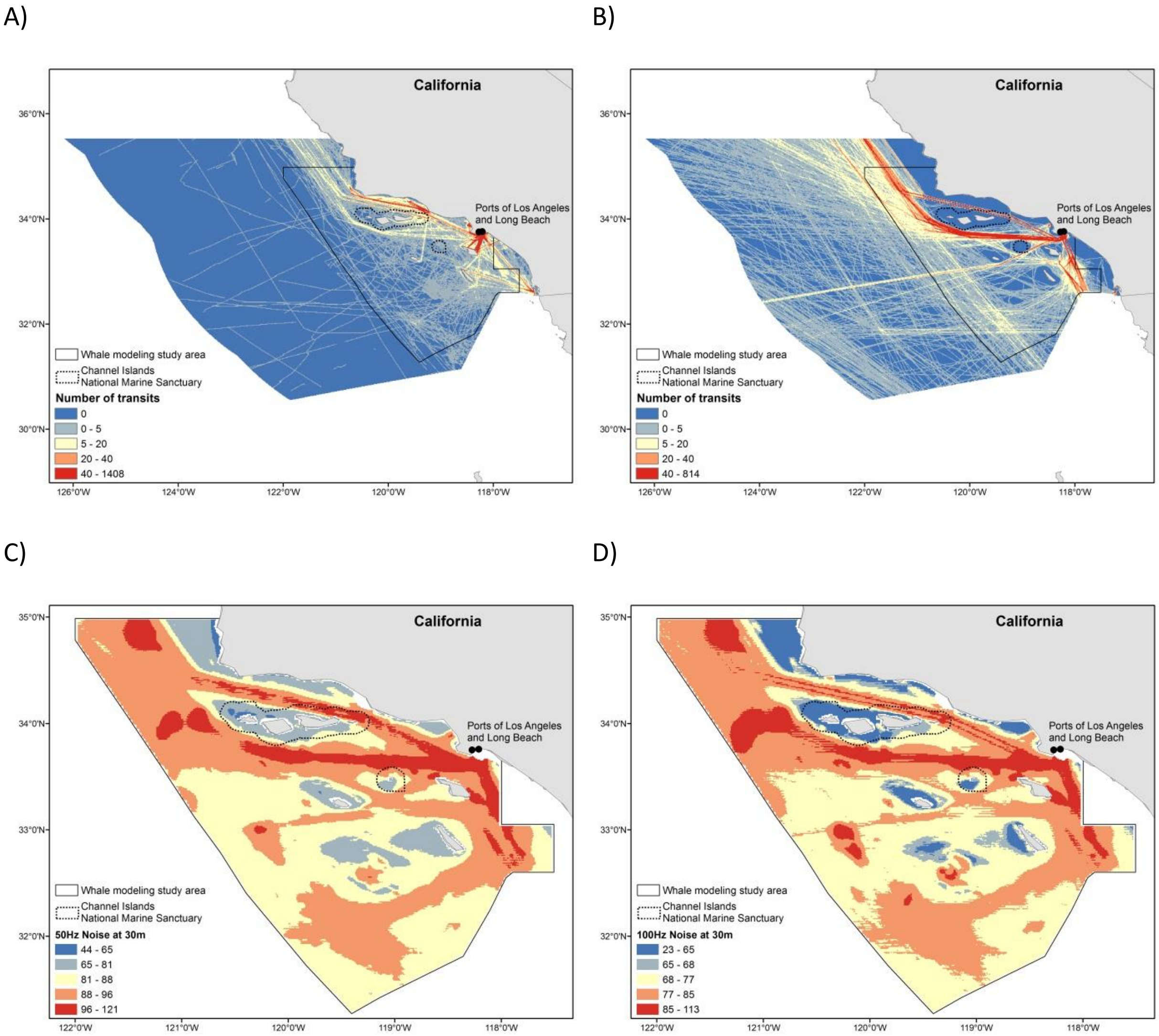

Figure 4-3. The number of transits by ships A) ≥ 18m and ≤ 120m in length and B) >200m and <=320m in length between August and November in 2009 was calculated in an area larger than the whale modeling study area to capture the influence of ships in surrounding waters in the noise predictions. Maps for the two other ship length categories (> 120m and ≤ 200m in length and > 320m in length, see text for details) are not shown because their traffic patterns are similar to the patterns seen for ships >200m and <=320m in length. Predicted C) 50Hz and D) 100Hz noise levels at 30m depth between August and November 2009. Noise predictions at both frequencies are categorized using an estimate of pre-industrial noise conditions (65dB) and the 10th, 50th, and 90th percentiles of the predictions. Noise predictions generally correspond to the traffic patterns for larger ships, although some influence from smaller ships can also be seen.

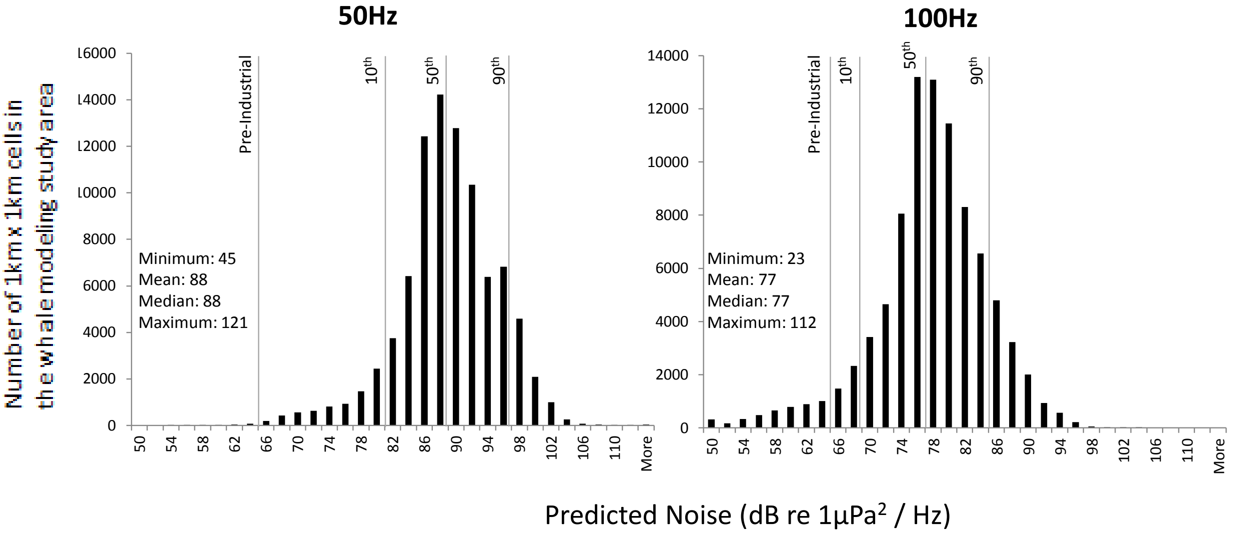

Figure 4-4. Histograms of 50 and 100Hz predicted noise levels within the whale modeling study area. The x-axis and summary statistics are in decibels (dBs). Thin gray lines mark the noise levels used in our analyses: pre-industrial noise below 65dB for both frequencies and the 10th, 50th (median), and 90th percentiles of predicted noise levels. The mean and median of the predicted noise levels were the same (within rounding) at both frequencies.

Co-occurrence of whale habitat and noise

Blue whale habitat was associated with the 200-m isobath (Redfern et al. 2013), which represents the shelf break in this region. The blue whale BIAs generally overlap with the higher densities predicted by the habitat model; however, the model predicts higher blue whale densities throughout a much broader offshore region (Fig. 4-2A). Almost no blue whale habitat, regardless of the data source used to define habitat, contained pre-industrial noise conditions and the majority of blue whale habitat contained predicted 50Hz noise levels associated with moderate, heavy, and extreme volumes of shipping traffic (Table 4-4). Noise risk hotspots occurred near the ports of Los Angeles and Long Beach, in the Santa Barbara Channel (including areas inside the CINMS), and in discrete offshore locations (Fig. 4-5A). In coastal waters off Point Conception, a blue whale BIA overlaps with a relatively quieter area associated with low volumes of shipping traffic.

Table 4-4. Whale habitat was defined using the highest 20% of densities predicted by a habitat model (Density), biologically important feeding areas (BIA; BIAs have not yet been identified for fin whales), and areas containing opportunistic sightings (Sightings). We estimated the percentage of each habitat type that contained predicted 50Hz (blue and fin whales) and 100Hz (humpback whales) noise levels associated with different volumes of shipping traffic (see Table 2 for the range of noise values in each category).

	Blue Whales			Fin Whales		Humpback Whales		
Volume of shipping traffic	Density	BIA	Sightings	Density	Sightings	Density	BIA	Sightings
Pre-industrial	0.3	1.3	0.1	0.0	0.0	18.9	52.4	25.4
Low	24.7	37.9	29.2	6.8	26.9	4.3	10.1	12.3
Moderate	36.8	26.2	18.3	35.9	16.4	14.2	21.2	29.0
Heavy	32.6	22.8	31.2	50.9	35.8	44.3	13.4	23.8
Extreme	5.6	11.9	21.2	6.4	20.9	18.2	2.9	9.6

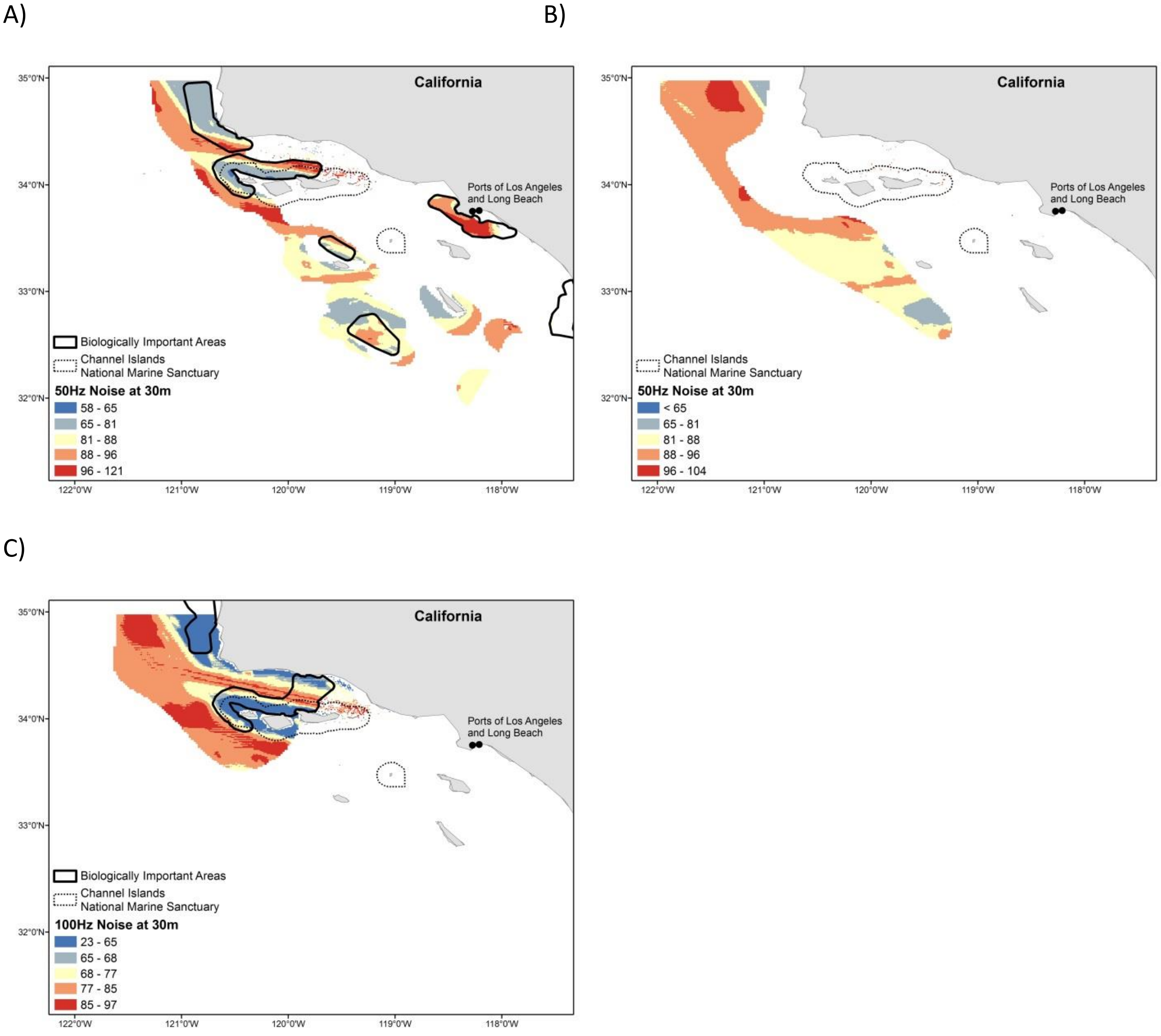

Figure 4-5. Predicted noise levels at 50Hz are shown in categories associated with different volumes of shipping traffic (< 65dB = pre-industrial; 65-81 = low; 81-88 = moderate; 88-96 = heavy; >96 extreme) for A) blue and B) fin whale habitat (i.e., the highest 20% of predicted densities, within BIAs, and in cells with opportunistic sightings). Fin whale BIAs have not yet been defined. No fin wale habitat contained predicted noise levels below 65dB. Noise at 100Hz is also shown in categories associated with different volumes of shipping traffic (< 65dB = pre-industrial; 65-68 = low; 68-77 = moderate; 77-85 = heavy; >85 extreme) for C) humpback whale habitat. Noise risk hotspots, areas where species habitat contained elevated noise, can be identified and represent areas where the acoustic environment for the species may be degraded by shipping noise. Quieter areas within species habitat can also be identified.

Fin whale habitat (Fig. 4-2B) occurred in offshore waters and generally had the least overlap with predicted 50Hz noise levels associated with pre-industrial and low volumes of shipping traffic (Table 4). In particular, no fin whale habitat contained pre-industrial noise conditions. Additionally, over 50% of fin whale habitat contained predicted 50Hz noise levels associated with heavy and extreme volumes of shipping traffic (Table 4-4). Noise risk hotspots occurred offshore of Point Conception and to the west and south of the northern Channel Islands (Fig. 4-5B).

Humpback whale habitat occurred in the northernmost portion of the whale modeling study area (Fig. 4-2C). The humpback whale BIAs overlap with the higher densities predicted by the habitat model; however, the model predicts higher humpback whale densities farther offshore than the BIAs (Fig. 4-2C). Humpback whale habitat contained a larger percentage of area associated with pre-industrial noise conditions, compared to blue and fin whales (Table 4-4). These quiet areas occurred in the CINMS and in coastal waters off Point Conception (Fig. 4-5C). Noise risk hotspots occurred primarily in offshore habitat, but also occurred in the Santa Barbara Channel and the CINMS (Fig. 4-5C).

Discussion

Predicted noise levels in southern California waters suggest high, region-wide exposure to shipping noise. For example, over 99% and 94% of the whale modeling study area contained predicted 50 and 100Hz noise levels, respectively, above our approximation of pre-industrial conditions. The predicted noise levels were broadly comparable to time series of ocean noise measurements made in central and southern California (Urick 1984, McDonald et al. 2008). The agreements and differences between predicted noise levels and the HARP measurements highlight the many sources of variability that influence predicted noise levels at a particular location, at particular frequencies, and within specific time periods.

In southern California waters, the differences between predicted and measured noise are likely strongly influenced by changes in shipping traffic. A decrease in the number of ship transits off southern California was observed as a result of the “great recession” that occurred between December 2007 and June 2009 (McKenna et al. 2012a). Traffic patterns also changed when the California Air Resources Board implemented the Ocean-Going Vessel Fuel Rule (hereafter, fuel rule) in July 2009. The fuel rule was intended to reduce air pollution by requiring large, commercial ships to use cleaner-burning fuels when traveling within 24 nautical miles of the mainland coast (Soriano et al. 2008). A majority of ships traveled through the Santa Barbara Channel in the TSS adopted by the IMO before implementation of the rule. Following implementation, a higher proportion of ships began traveling south of the northern Channel Islands to reduce the time spent using more expensive, cleaner fuels (McKenna et al. 2012a).

Our noise models were developed using the number of ship transits between August and November 2009. In contrast, the HARP measurements were made in November 2009. The much higher (5-12dB) differences between predicted and measured noise at the northern HARP likely occurred because the HARP measured reduced traffic in the Santa Barbara Channel during November, compared to the higher traffic within the Santa Barbara Channel during the earlier part of time period used in the noise models (August through November). The smaller differences (less than 3dB) between predicted and measured noise at the southwestern HARP likely occurred because the increased traffic traveling south of the northern Channel Islands was measured by the HARP during November and incorporated in the later part of time period used for the noise models (August through November).

The differences in predicted versus measured noise may also be the result of ship source levels. The noise models used ship source levels that were estimated from data collected in the 1970s and 1980s (Carey & Evans 2011); these source levels may overestimate the noise produced by the modern fleet. The 1Hz-band ship source levels used in the noise models are approximately 10-15 dB higher than some more recent, broader-band estimates of source levels for newer ship designs (e.g., McKenna et al. 2012b). Improvements in the noise models could also be made by incorporating ship speed in predicted ship source levels. High-resolution, spatially explicit maps of vessel speed can be derived from AIS data. However, algorithms to estimate changes in source level from speed exist for a small number of vessel types and length classes (e.g., container ships; McKenna et al. 2013). Finally, the noise models could be improved by increasing the resolution of bottom-type data for waters off Southern California because sound propagation is influenced by bottom type. As more measurements of ocean noise become available in southern California waters, the comparison between predicted and measured noise should be expanded spatially and temporally.

Our risk assessment identified several areas in southern California waters where the acoustic environment may be degraded for blue, fin, and humpback whales because their habitat overlaps with predicted areas of elevated noise from shipping traffic. In particular, the Santa Barbara Channel contained higher predicted densities and biologically important feeding areas for blue and humpback whales that overlap with elevated noise from the TSS. The TSS was changed in 2013 to reduce the risk of ships striking whales. To understand how this change affects the overlap between whale habitat and noise, risk assessments must be conducted using traffic data collected after this change. Areas offshore of Point Conception, west of San Miguel Island, and south of San Miguel Island and Santa Rosa Island contained higher predicted densities of all three species and elevated noise from commercial shipping.

In general, fin whale habitat was predicted to occur in noisier waters than blue and humpback whale habitat. The habitat models developed by Redfern et al. (2013) predict higher fin whale densities farther offshore than higher blue whale densities, resulting in a higher overlap between fin whale habitat and predicted 50Hz noise levels. Humpback whale habitat generally occurred in waters less influenced by noise than blue and fin whale habitat because humpback whales occur closer to shore, where predicted 50 and 100Hz noise levels were lower. In general, predicted 100Hz noise levels were lower than 50Hz levels because large ships produce less noise at 100Hz than 50Hz (Carey & Evans 2011). Additionally, 100Hz can be considered a lower bound for assessing noise risk to humpback whales because their conspecific vocalizations span a broad range of low frequencies. The co-occurrence of blue and fin whale habitat and predicted 50Hz noise levels raises concerns about the quality of their acoustic environment and how it supports their communication at extreme low frequencies. These long-lived animals evolved to take advantage of acoustic conditions that this study estimates have been entirely (fin whales) to near entirely (blue whales) eliminated within the habitats most important to sustaining their presence in Southern California waters.

Our risk assessment also identifies two places where biologically important blue and humpback whale feeding areas overlap with lower predicted noise levels: in coastal waters off Point Conception and in the CINMS. When considering the entire CINMS, it represents a relatively quieter area within the generally noisy southern California waters. In particular, approximately half of the CINMS contained predicted noise levels associated with pre-industrial and low volumes of shipping traffic. Noise has not been directly managed in the CINMS; instead, areas containing reduced noise levels in the CINMS are likely an ancillary benefit of the Area to be Avoided (ATBA) that was created around most of the CINMS by the IMO in 1991 to reduce groundings and pollution risks. Ships over 300 gross tons are also prohibited from operating within 1nmi of any of the Channel Islands unless they are transporting people or supplies to an island or engaged in fishing or kelp harvesting. As a result of the ATBA and restrictions close to the islands, ship traffic and, concomitantly, elevated noise in the CINMS has been primarily restricted to where the TSS overlaps with the Sanctuary's boundaries (Fig. 4-3). This overlap results in approximately 22-24% of the CINMS containing predicted 50 and 100Hz noise levels in or above levels associated with heavy volumes of shipping traffic.

Our risk assessment framework can be used to evaluate the consequences of potential management actions and further changes in shipping traffic. For example, noise associated with different ship routing options could be modeled and used to quantify the resulting changes in the co-occurrence of whale habitat and noise. Additionally, a time series of annual noise predictions could be developed to understand changes in risk associated with changes in shipping traffic. The next steps for the risk assessment are to incorporate uncertainty and develop metrics to estimate the consequences of the risk. Explicitly identifying uncertainty helps managers understand the degree of confidence they can place in the risk assessment and helps to prioritize future data collection efforts (Hope 2006).

There is uncertainty associated with both the predicted species densities and noise levels used in our risk assessment. The uncertainty in the predicted species densities arises primarily from interannual variability in species distributions (Redfern et al. 2013). This interannual variability is caused by changes in oceanographic conditions on annual (e.g., the El Niño Southern Oscillation), decadal (e.g., the Pacific Decadal Oscillation), and longer time scales (e.g., climate change). This uncertainty can be reduced by extending the data time series, using finer-resolution habitat data, and incorporating prey data. There is also a need to examine the seasonality of the risk estimates because fin whales are present off Southern California all year and some blue and humpback whales may have arrived before or remained after the period in which the data were collected. Finally, the risk assessment could be conducted using the maxima or minima of predicted noise levels during the August to November time period, in addition to predicted values averaged over this time period. It could also be expanded beyond the single frequencies we selected to capture the variable contributions from shipping to noise using one-third octave bands or audiogram weighting (e.g., the approach developed by Erbe et al. 2014).

The current risk assessment identifies areas of co-occurrence between whale habitat and noise from commercial ships. Metrics are needed to estimate the consequences of this co-occurrence. Previous studies have estimated the loss of potential communication opportunities among individuals (e.g., Clark et al. 2009, Hatch et al. 2012) to quantify the influence of chronic noise on large whales. Applying this metric to Southern Californian waters would further highlight frequency-specific implications of noise for transmission of specific call types. The fitness implications of locally degraded acoustic environments can also be considered within population viability models that include other environmental determinants of foraging and mating success and that account for trends in those variables (e.g., climate change). Finally, stress hormone levels and other health and demographic indicators could be compared among populations, subspecies, or sister species that occur in areas with different long-term noise conditions.

Current U.S. regulation of noise under the Endangered Species Act and Marine Mammal Protection Act does not include impacts associated with chronic noise from shipping. Consequently, new and different types of management may be needed to address low-frequency ocean noise. Place-based management focuses on a specific ecosystem and the range of activities that impact it (Hatch & Fristrup 2009). Our risk assessment highlights how noise is affected by several place-based management techniques: a National Marine Sanctuary, an IMO Area to be Avoided, and an IMO traffic separation scheme. Previous evaluations concluded that pursuit of sanctuary authority to directly manage low-frequency noise would face obstacles and would not address the influence of shipping noise beyond sanctuary boundaries (Haren 2007). However, our risk assessment suggests that the IMO's designation of most of the CINMS as an ATBA has resulted in lower noise in many areas of the sanctuary, compared to southern California waters in general. Consequently, a variety of international management tools focused more broadly on reducing spatial overlap between human activities and vulnerable marine areas may provide opportunities for successful noise management.

Traffic Separation Schemes concentrate shipping traffic and noise. Where the TSS occurs in the CINMS, resources are exposed to high levels of low-frequency noise creating a gap in the sanctuary's placed-based protection. This gap is of particular concern due to the biologically important blue and humpback whale feeding areas that occur in this region. Offshore areas containing the highest predicted densities of fin whales were also heavily impacted by noise. Noise in heavily impacted biologically important areas could be reduced by designating these areas as Particularly Sensitive Sea Areas (highlighting their need for special protection) and implementing management measures that require or recommend that ships operate in a manner that reduces noise.

Biologically important areas for humpback and blue whales in coastal waters off Point Conception contained some of the remaining quiet areas in southern California waters. Areas that support feeding and breeding for these populations and that are currently quieter, relative to regional levels, could be designated as Areas to be Avoided to ensure they remain free of high levels of shipping traffic. Studies of ship-strike risk have also been conducted in southern California waters (Redfern et al. 2013). Strategies for reducing ship-strike risk have been implemented in many parts of the world and include moving or creating a TSS, moving or creating voluntary shipping routes, and reducing ship speed. These strategies may also reduce noise. Hence, the consequences of low-frequency noise should be considered with ship strikes in cumulative risk assessments and marine spatial planning. Most placed-based management strategies are static in space and time. There is also a need to consider dynamic management strategies to respond to the spatial and temporal variability inherent in marine mammal distributions and human use patterns.

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Case Study 2:
Managing Noise Impacts on Spawning Areas Used by Acoustically Sensitive and Commercially Important Fish and Invertebrate Species

This case study provides a place-based context for examining recommendations from Chapter 1 (expanded focus and attention to NOAA-managed and acoustically sensitive fishes and invertebrate species), Chapter 2 (extended use of existing authorities to address noise impacts to acoustic habitats for sensitive fish and invertebrate species) and Chapter 3 (prioritized development of NOAA-maintained long-term passive acoustic monitoring capacity).

Problem Formulation

Target Species and Habitat:

Many commercially-important fish species that NOAA is charged with managing produce sound or are known to use sound during critical life stages (see Chapter 1 & Appendix A). Along the U.S. Atlantic seaboard, sound production or sensitivity is well documented in the Northeast for Atlantic cod and haddock (Family *Gadidae*) and in South Atlantic Bight for members of the snapper-grouper complex (e.g., Families *Serranidae* and *Lutjanidae*), grunts (Family *Haemulidae*), and croakers and drums (Family *Sciaenidae*), among other species (Normandeau Associates, Inc., 2012; Hawkins et al., 2014). Some of these species are known to make sounds including, though not always exclusively, during spawning (e.g., cod, haddock, red drum, red grouper, black grouper) while others are known to produce sounds, though those sounds have yet to be linked to reproductive activity (e.g., gag grouper, grunts). Hearing sensitivity has not been documented for most of these species, but is predicted to support their detection of low frequency signals, including, but not limited to, the sounds they produce (mostly less than 1000Hz). Hearing has been well studied in Atlantic cod, which are known to very effectively detect as well as avoid low frequency noise sources (Chapman & Hawkins 1973). Some of these species have evolved mechanical connections between the swim bladder (or other gas bubble) and the inner ear (i.e., red drum), or have gas bladders that are close to the ear (i.e., red snapper) (Hawkins & Popper 2014). There is evidence that such connections and proximity can increase hearing sensitivity (ibid). Although best studied as adults, the larvae of some of these species are documented to be sensitive to sound (e.g., cod, red snapper; Simpson et al. 2005) and recently have been found to produce sound as well (e.g., gray snapper; Staaterman et al., 2014). Thus, the acoustic condition of the habitats that support vulnerable early life stages for these acoustically active or sensitive species, such as spawning adults, larvae and juveniles, is relevant to NOAA's fishery science and management actions.

Cod and haddock stocks in New England and snapper and grouper stocks in the South Atlantic are managed by NOAA and regional Fishery Management Councils, with additional inshore management by state fishery agencies. In the Atlantic, red drum is managed exclusively by the Atlantic States Marine Fishery Commission (ASMFC). Most of these Atlantic stocks are considered overfished and/or overfishing is occurring; thus NOAA or state managers (in the case of red drum) are tasked with managing their return to sustainable population levels. The need to protect critical life stages (i.e., spawning adults, pre-settlement and settlement stage larvae and juveniles) is well understood by state and federal fishery managers as playing an important role in stock recovery.

The need to protect spawning and juvenile cod and haddock in the Gulf of Maine beyond current essential fish habitat (EFH) designation is gaining recognition within the Northeast Fisheries Management Council (NEFMC). The NEFSC's Closed Area Technical Team is currently evaluating various options for new or amended spatial and temporal closures to protect spawning or juvenile fishes as part of their revision of current habitat protections in the region (Figure 4-6A; NEFSC CATT 2014). The

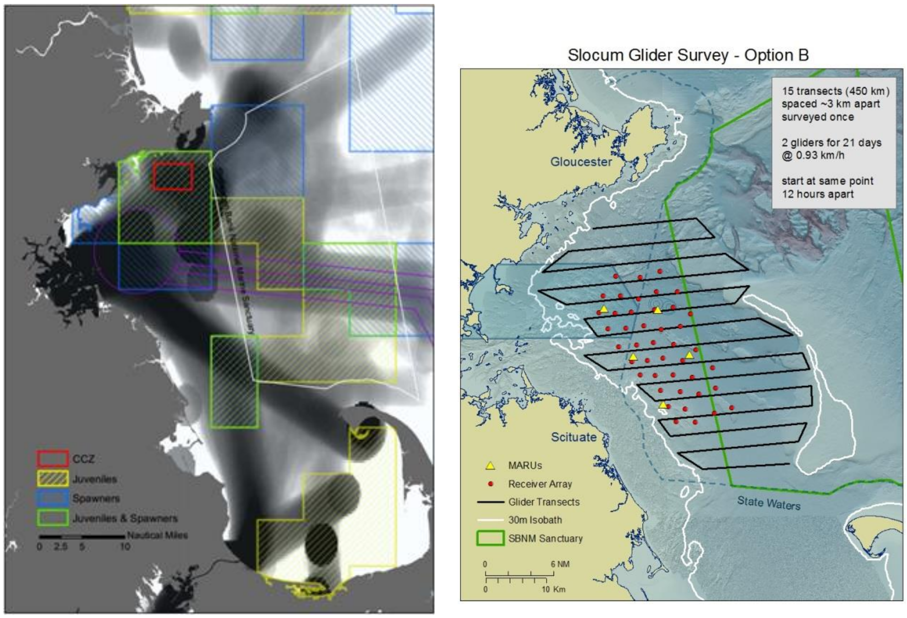

Figure 4-6. Massachusetts Bay off the Northeast Coast of the U.S. (A) Proposed areas associated with spawning Atlantic cod, juvenile Atlantic cod and both (spawning and juvenile) as presented by the Closed Area Technical Team to the Northeast Fisheries Management Council (April 2013); Cod Conservation Zone (CCZ) created by the Commonwealth's Division of Marine Fisheries to protect spring cod spawning activity; large commercial vessel traffic via Traffic Separation Scheme in purple outline and as a density field from Automatic Identification System tracking system in black; boundaries of the Stellwagen Bank National Marine Sanctuary (white).
(B) Instrumentation associated with 2014-2017 collaborative research to further identify spawning cod areas in Massachusetts Bay.
Figures: Michael Thompson, NOAA SBNMS; Micah Dean, Mass DMF

Commonwealth of Massachusetts' Division of Marine Fisheries has identified a predictable inshore area used by spawning cod in the spring, and has established a closure known as the Cod Conservation Zone to protect this site during active spawning. NOAA (Northeast Fisheries Science Center and Stellwagen Bank National Marine Sanctuary) is currently participating in a collaborative effort to identify additional spawning locations used by winter spawning cod, and to identify haddock spawning areas, using both passive (listening) and active (telemetry) acoustic techniques (Figure 4-6B). New spatial protection areas for spawning and juvenile cod could be included in the NEFSC's finalization of Omnibus Habitat Amendment 2.

In the South Atlantic Bight, the South Atlantic Fishery Management Council (SAFMC) has established EFH and habitat areas of particular concern (HAPCs) to increase protections for snapper-grouper complex species both offshore in areas with known spawning aggregations and inshore in areas known to support juveniles (Figure 4-7). Offshore HAPCs include eight marine protected areas (MPAs) established by the SAFMC in 2009 through Amendment 14 to the Snapper Grouper Fishery Management Plan (http://www.safmc.net/managed-areas/marine-protected-areas). Snapper-grouper spawning is known to occur within and around several of these MPAs (SAFMC MPA Expert Workgroup 2013). It is largely unknown whether spawning activity taking place in offshore shelf-break habitats such as these is accompanied by sound production, and if so, by which species. In 2014, researchers from NOAA (Southeast Fisheries Science Center-SEFSC and National Centers for Coastal and Ocean Science-NCCOS), the University of South Florida, Loggerhead Instruments and NC State University deployed an autonomous ocean glider outfitted with hydrophones to survey the continental shelf break off the Carolinas, Georgia and Northern Florida to attempt to document areas used for spawning by acoustically-active fishes on the shelf break, including current MPAs. Sounds produced by red grouper (see Nelson et al., 2011) were recorded in and around the Northern South Carolina and Edisto MPAs off the coast of South Carolina (Figure 4-7A).

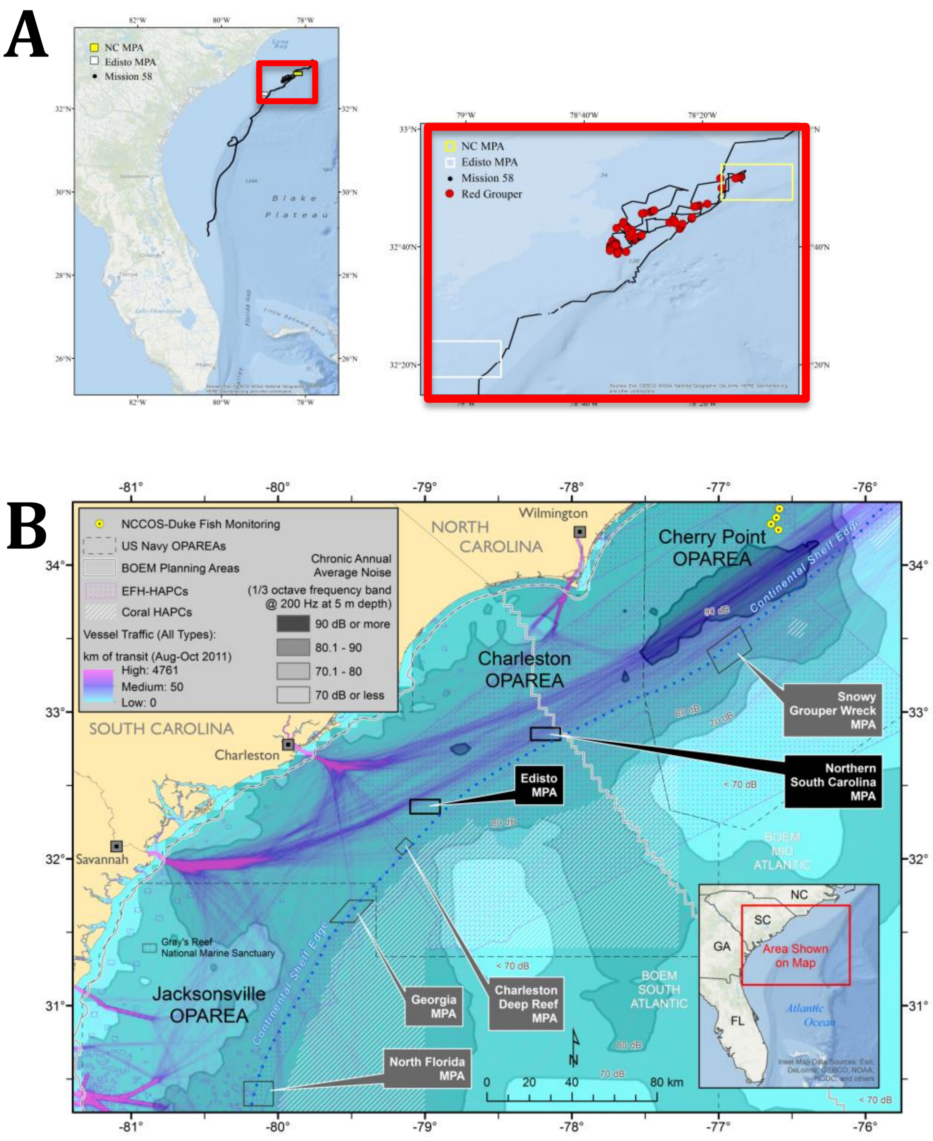

Figure 4-7. Offshore North and South Carolina, South Atlantic Bight, U.S.

(A) Track of passive acoustic glider relative to two SAFMC MPAs; red dots in inset indicate glider locations where red grouper sounds were detected.

(B) Annual average predicted shipping noise (SoundMap) and large commercial vessel density (3 month snapshot) from Automatic Identification System data relative to EFH Habitat Areas of Particular Concern and Marine Protected Areas (MPAs) designated by the South Atlantic Fishery Management Council (SAFMC); BOEM planning areas for offshore energy development (oil and gas, renewable energy, and marine mineral); U.S. Navy operating areas; research stations being used by NOAA NCCOS and Duke University researchers to study impacts to fishes associated with 2014 NSF seismic surveys.

Figures: Carrie Wall and David Mann, Loggerhead Instruments; T.J. Moore, NOAA SWFSC

Juvenile gag grouper, black sea bass and black grouper are known to feed and shelter in estuarine environments, such as the coastal oyster reefs and inlets of Pamlico Sound, North Carolina (Figure 4-8A). These waters have been designated as HAPC for the snapper-grouper complex (inclusive of all Primary and Secondary Nursery Area designated in North Carolina). The acoustic condition of inshore HAPC that supports young and acoustically sensitive (black sea bass) and active (gag and black groupers) snapper-groupers is thus of additional concern for NOAA science and management. Though not managed by NOAA, similar areas are used by state-managed (ASMFC) red drum as spawning and nursery habitats (http://www.asmfc.org/uploads/file/redDrumHabitatFactsheet.pdf). Red drum and other *sciaenid* spawning habitats have been identified in Pamlico Sound using passive acoustics methods (Luczkovich et al., 2008; Figure 4-8). Proposed studies aim to use passive acoustic gliders to survey large areas of Pamlico Sound that are less well understood (J. Luczkovich, personal communication). Additional proposals are under consideration that would assess impacts of ongoing bridge construction in Beaufort, North Carolina (a main waterway into Pamlico Sound) on resident acoustically active spawning fishes and dolphins (D. Nowachek, personal communication). Estuarine soundscapes within Pamlico Sound have also been the focus of more holistic examination to understand whether reef and non-reef locations supporting different acoustically active species, including snapping shrimps and *sciaenids*, are producing important acoustic cues for these and additional fish and invertebrate species relying on these habitats (e.g., oysters and juvenile fishes; Lillis et al., 2014).

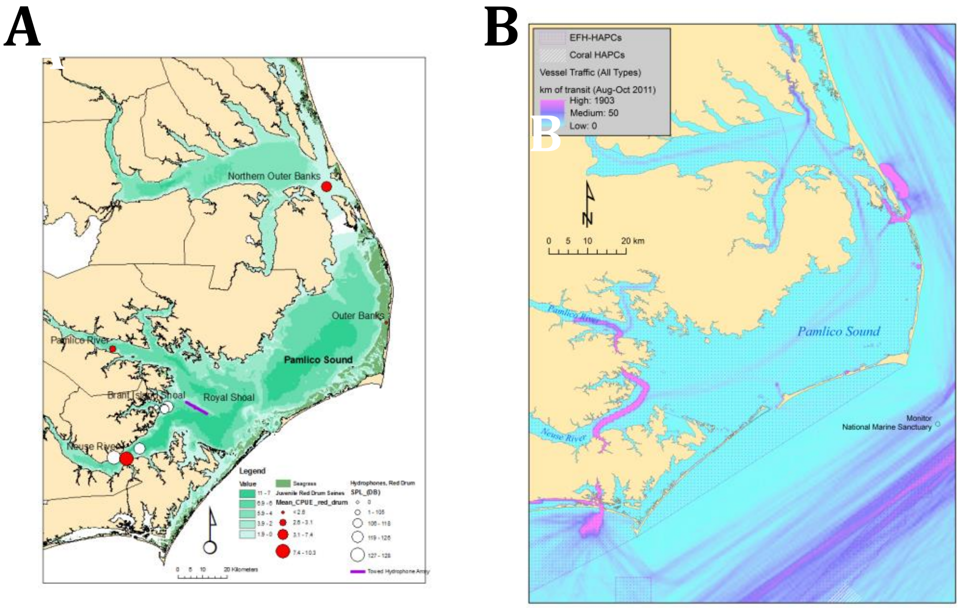

Figure 4-8. Inshore Cape Hatteras to Cape Lookout, Pamlico Sound, North Carolina.
(A) Known red drum spawning areas, based on passive acoustic detections of the advertisement sounds produced by males, larval fish collections and North Carolina DMF seine surveys.
(B) Vessel traffic snapshot (3 months) based on Automatic Identification System data; EFH Habitat Areas of Particular Concern designated by the South Atlantic Fishery Management Council (SAFMC) to support early life stages for snapper-grouper complex.
Figures: Joseph Luczkovich (East Carolina University); T.J. Moore, NOAA SWFSC

Current Status of Ocean Noise Information:
Vessel noise is known to dominate background noise levels within frequency bands used by spawning Atlantic cod and haddock in Massachusetts Bay. Ongoing passive acoustic research conducted by NOAA (Northeast Fisheries Science Center-NEFSC and Stellwagen Bank National Marine Sanctuary-SBNMS) and collaborators (e.g., Cornell University) has documented low-frequency noise contributions from different types of vessels within the SBNMS and Massachusetts Bay. Sound propagation modeling predictions based on Automatic Identification System (AIS) large commercial ship tracking information and empirical measurements (low-frequency sound recordings) are both available in the region at high resolutions (daily for multiple years, ~1 kilometer grid and 10-2000Hz). Fishing vessel and whale watching vessel noise implications have also been estimated in this area. Model predictions for annual average offshore contributions to the region are also available via the SoundMap project (http://cetsound.noaa.gov/sound_data). NEFSC, SBNMS, and Woods Hole Oceanographic Institution, as part of collaborative research with the Commonwealth of Massachusetts' Division of Marine Fisheries, The Nature Conservancy and commercial fishermen, are using passive acoustic gliders and bottom mounted recorders to identify cod spawning areas (Figure 4-6). This effort will provide additional data to support assessments of background noise relative to spawning Atlantic cod sound production.

Chronic low-frequency noise levels within offshore spawning locations in the South Atlantic Bight such as the Northern South Carolina and Edisto MPAs are not well documented. SoundMap predicted annual average influence from large commercial shipping noise at a regional scale (Figure 4-7; http://cetsound.noaa.gov/sound_data). Higher resolution estimates of shipping noise based on AIS data are not currently available, and are necessary for evaluation of impacts within smaller areas such as these MPAs. However, both SoundMap and distribution of AIS-tracked vessels suggests significant low frequency commercial traffic noise along the shelf break, particularly within the Northern South Carolina MPA (Figure 4-7). Influence from other traffic types that may be relevant to offshore vessel noise signatures, including cumulative fishing vessel, research or ecotourism traffic, is unknown. Recent passive acoustic work by NOAA and collaborators could begin to address this uncertainty; in addition to identifying areas of use by acoustically active fishes, glider data could be used to assess anthropogenic contributions to background noise levels.

Two other known sources of noise in the South Carolina MPAs have less overlap with the low frequencies produced by offshore spawning reef fish or are short-term activities that have limited influence on the chronic condition of acoustic habitats. That said, they have the potential to provide NOAA with important data resources for understanding the acoustic status of these areas. First, both the Northern South Carolina and Edisto MPAs are within the U.S. Navy's Charleston operating area (OPAREA). The main active acoustic sources in use in the area are mid-frequency sonars (Atlantic Fleet Training and Testing Environmental Impact Statement-AFTT EIS, http://aftteis.com/). As part of AFTT baseline monitoring, the Navy has funded extensive passive acoustic monitoring efforts, including bottom-mounted acoustic recorders off Cape Hatteras, Onslow Bay and Jacksonville, to better understand impacts from sonars and other range activities on whales and dolphins. Although not directly overlapping with currently protected snapper-grouper spawning habitats, some of this effort has recorded low frequencies in addition to higher frequencies of primary focus. These data could potentially be mined to provide information on shelf-break soundscape conditions that are relevant to these stocks. Second, a seismic survey using a 2D air gun array (a low frequency source) was conducted in 2014 by NSF and transited through EFH HAPC off Cape Lookout, North Carolina. To monitor impacts to fishes in this area, including some that are acoustically active, researchers from NCCOS and Duke University deployed time-lapse video and acoustic recorders at stations close to the survey line. Such research will provide regionally-specific information to assist NOAA managers in their evaluations of the impacts of new proposals for more pervasive commercial seismic survey activity on managed fish stocks and habitats, including both physical injury and biologically (or fishery) significant behavioral responses and longer-term impacts to acoustic habitats within EFH HAPCs.

The dominant anthropogenic contributors to low frequency noise within inshore spawning and nursery habitats of Pamlico Sound are not well documented. Soundscape analyses completed thus far have been limited in time and space and have focused on natural contributions, removing anthropogenic signatures (Lillis et al., 2014). Noise from human activities in these shallow water estuarine environments is predicted to be highly variable depending on local source distributions, such as proximity to areas with seasonally high recreational and commercial small vessel use, onshore road and bridge traffic or nearshore construction activities (i.e., pier and harbor work). Physical environmental factors such as sediment types, topography and oceanography will also influence local acoustic signatures, reducing introduction of noise from surrounding areas in some cases, while augmenting noise in other areas. AIS vessel traffic information is known to be a limited representation of smaller and non-oceangoing commercial and recreational vessel types common in inland waterways. However, evaluation of these data does reflect overlap between an area of known importance to spawning red drum and commercial, pleasure and military traffic transiting between Beaufort and New Bern, North Carolina, through the Adams Creek Canal (Figure 4-8). Continuing passive acoustic work by academic scientists from East Carolina, North Carolina State and Duke Universities seeks to further describe priority acoustic habitats for fishes in this region.

Next Steps

Activity-Specific Mitigation and Monitoring:

As discussed above, current or future human activities that are influencing, or are likely to influence, the longer-term conditions of acoustic habitats of spawning sites discussed here could include transiting vessels, offshore energy exploration and development, and some activities associated with military training. Impacts from proposed offshore, non-fishing activities on EFH, including HAPCs, are addressed through EFH consultations between action agencies and NOAA Fisheries. Due to the high ecological importance of these areas, impacts on HAPCs are given heightened scrutiny during EFH consultations. EFH consultations result in conservation recommendations provided to action agencies that would avoid, minimize, or mitigate impacts on the habitats of Federally-managed species of fishes and invertebrates. These recommendations can include spatial and temporal measures (e.g., avoiding specific time periods or areas to reduce impact) and monitoring (e.g., water column sampling). To date, NOAA Fisheries' EFH consultations along the East Coast have primarily addressed acute noise impacts from activities such as pile driving in nearshore habitats, but have yet to address chronic noise impacts that could disrupt sensitive behaviors such as settlement by young fishes, spawning, or foraging. Additionally, NOAA engages in several regional initiatives aimed at promoting marine spatial planning objectives that include dialog and information sharing with other federal, state and tribal governmental interests, as well as additional stakeholders. These venues, both informally and formally, are increasingly providing mechanisms for NOAA to inform early planning stages and siting decisions relative to trust resources and for NOAA to identify partnerships to address key applied research needs.

Vessel Noise

Transiting vessels are conspicuously exempt from current NOAA noise exposure assessment and regulation (Hatch & Fristrup 2009). The general coming and going of international maritime traffic does not require federal action by a U.S. agency that could trigger EFH consultation. That said, periodic large-scale evaluations by the U.S. Coast Guard (USCG) or Maritime Administration (MARAD), such as coast-wide Port Access Route Studies, offer opportunity for interagency dialog regarding potential impacts to

NOAA trust resources. To date, Port Access Route Studies have included evaluation of noise impacts to marine mammals, but not to fishes. In addition, NOAA and the USCG have worked together in several regions to shift, extend and narrow shipping lanes. These efforts have focused on reducing vessel-whale collisions, but with additional interest in reducing noise exposure. Such evaluations necessitate comprehensive evaluation of impacts to multiple stakeholders as well as multiple marine taxa to ensure that proposed traffic changes will not create unintended consequences. **NOAA could work with the USCG to evaluate the chronic impacts of commercial vessel traffic on the acoustic conditions of federally designated areas (i.e., EFH) to protect acoustically active or sensitive fishes.** In many cases, current baseline data on noise influence within areas designated or being considered by FMCs to protect fishes that are acoustically active during spawning is insufficient to support route alteration proposals, and thus focus could be engaging the USCG in discussions regarding NOAA's development of targeted noise monitoring programs (see below).

Both the average size and the overall number of ships accessing major East Coast ports is predicted to increase with the completion of an enlarged Panama Canal (MARAD 2013). More and larger ships will increase the levels of low frequency noise on the eastern seaboard, particularly close to major shipping lanes (e.g., traffic separation schemes) and surrounding the East Coast ports that either can already accommodate this new traffic (e.g., Baltimore, MD, Norfolk, VA) or will be able to do so by the time the expanded Panama Canal opens (Miami, FL, and New York/New Jersey). Other East Coast ports are making preparations for dredging to channel depths of 45 feet or more, depths that can accommodate many of the Post-Panamax ships (including Savannah, GA, Charleston, SC, Wilmington, NC, and Boston, MA). Post-Panamax noise levels can thus be expected to increase within spawning locations within Massachusetts Bay and in shipping routes off the Carolinas. It is currently unclear whether, and if so what, federal actions may be necessary to facilitate this growth in East Coast traffic that could be used to evaluate possible route or operational measures to reduce chronic noise exposure in places of importance to NOAA trust resources. **NOAA could work with the USCG and MARAD to evaluate impacts to the acoustic conditions of key fish spawning locations associated with federal actions associated with predicted growth in East Coast traffic.**

Finally, since 2007, NOAA has been working with the USCG to lead a correspondence group at the United Nations' International Maritime Organization (IMO) focused on the development of technical guidelines for quieting commercial vessels. This work progressed significantly in 2014, when the IMO finalized these guidelines, producing a voluntary mechanism by which ship builders and operators could reduce noise emanating from large commercial ships (IMO MEPC 2014). Interests in noise reduction in any local area must include international action to address wide-ranging shipping noise influence. **NOAA could continue work with the USCG at the United Nations' International Maritime Organization to encourage the implementation of new guidelines to quiet commercial vessels.**

Offshore Energy Exploration and Development

The Bureau of Ocean Energy Management (BOEM) produced a Record of Decision on July 11, 2014, following the release of a final programmatic Environmental Impact Statement (BOEM 2014) that renewed geological and geophysical surveying activity in the Atlantic. NOAA acted as a cooperating agency in the EIS analysis. NOAA Fisheries' Habitat Conservation Divisions in the Southeast and Northeast submitted a joint letter to BOEM on the EIS in 2012 which requested that EFH consults be conducted on individual surveys as received by BOEM for permitting. A similar request was made by the Office of National Marine Sanctuaries, and the finalized EIS includes both determinations. Noise generated by Atlantic geological and geophysical surveys has the most potential to influence the shelf break spawning areas discussed here. With potential EFH consultations, probabilities of acute injury to fishes will be evaluated close to survey lines as needed. However, these surveys will increase the level of background noise over a much larger area and could, therefore, disrupt activities that rely on acoustic signals, such as spawning, at far greater distances from the survey lines. Such effects have not yet been addressed. Should these surveys lead to the development of oil and gas resources, other noise sources, associated with the building and operation of platforms, both acute and chronic, will be introduced with the potential for associated acoustic effects on spawning behaviors.

NOAA could work with BOEM to assess potential impacts associated with proposed offshore energy exploration and development activities to the acoustic conditions of key spawning locations for acoustically active and sensitive fishes in the Mid- and South Atlantic. EFH Conservation Recommendations could include spatial (set-back distances, buffer zones and exclusions where necessary) or temporal (avoidance of key spawning time periods) mitigation options. In many cases, current baseline data on noise levels within areas designated or being considered by FMCs to protect fishes that are acoustically active during spawning may be insufficient to support mitigation development. Thus, EFH consultations may focus on presenting monitoring recommendations that can serve to improve NOAA's knowledge base in places of importance and guide adaptive management. The SAFMC is currently focused on expanding spatial protections for offshore spawning activity of key snapper and grouper species. Further passive acoustic work would inform these designs. Understanding of activity-specific impacts requires longer term monitoring investment to understand baseline conditions, a gap that could be addressed by increasing NOAA-maintained PAM capacity (see below).

Military Training Activities

NOAA currently works with the U.S. Navy to reduce noise impacts to marine mammals and endangered species and to resources within National Marine Sanctuaries associated with AFTT activities, including the use of sonars and other sound-producing sources. To date, the impacts of these same activities on acoustically-sensitive fishes have received less attention. **NOAA could work with the U.S. Navy to assess whether such patterns of training activity overlap federally designated areas (i.e., EFH HAPC) that protect acoustically active or sensitive spawning fishes.**

NOAA-Funded or Conducted Research

Documentation of baseline noise conditions as well as improved data on the use of sound by fishes within these sites will be necessary to support management action. As indicated above, NOAA (NEFSC, SEFSC, NCCOS and NOS-SBNMS) is actively engaged in research that responds to rising concern regarding noise impacts to key East Coast fish stocks. Some of these projects have historically been supported by non-NOAA funding but have recently begun to be supported internally (e.g., cod spawning research in Massachusetts Bay) while others are actively seeking funding both inside and outside the agency (e.g., NCCOS-Duke seismic research, Duke bridge-construction/pile driving research). Phase I of the development of a NOAA-maintained Noise Reference Station (NRS) network includes a sensor within the Stellwagen Bank National Marine Sanctuary that will be used to characterize trends in acoustic habitat quality for cod and haddock, and other acoustically active/sensitive species. Such capacity is not currently available for offshore South Carolina sites (the NRS in South Atlantic region is deployed off the central coast of Florida); however, NEFSC and Duke researchers are currently collaborating to develop PAM capacity in the South Atlantic Bight to establish baseline noise conditions relative to protected resource (e.g., cetacean) management concerns. While non-NOAA researchers are in position to address current gaps in knowledge of noise conditions in Pamlico Sound their research has historically highlighted state rather than federally managed species (e.g., red drum) and thus has targeted state agencies for funding and collaboration**.**

NEFSC, NOS-SBNMS and OAR-PMEL could continue to collaborate with key nongovernmental research partners (e.g., Massachusetts Division of Marine Fisheries, Woods Hole Oceanographic Institution) to identify locations of key long-term PAM interest for spawning cod and haddock in Massachusetts Bay.

NEFSC, SEFSC, NCCOS and Duke University could collaborate to incorporate priority locations for offshore spawning fishes (such as the MPAs discussed here) within protected resource-driven plans to develop PAM capacity on the shelf break in the Mid- and South Atlantic. These parties could also assess whether PAM data associated with the Navy's AFTT monitoring programs could be used to inform baseline characterization of low- frequency noise levels in key offshore Mid- and South Atlantic spawning areas for acoustically active or sensitive reef fishes, and if so, what resources would be necessary to derive metrics of interest.

SEFSC and NCCOS could collaborate with North Carolina DMF and key nongovernmental research experts (e.g., North Carolina State University, East Carolina University, Duke University) to identify locations of common passive acoustic monitoring interest in and around Pamlico Sound.

Support for developing PAM capacity at these prioritized locations could be included in NOAA's plans for phased deployment of Noise Reference Stations (see Chapter 3), within funding by NOAA programs that support fishery science (i.e., Fisheries Collaborative Research, Saltonstall-Kennedy Grants) and acoustic or coastal science (i.e., NOAA Ocean Acoustic Program and Sea Grant) and within dialogs with action agencies via EFH consultation. Data resulting from monitoring conducted by NOAA could be included in PAM archival efforts (see Chapter 3) to ensure that is accessible to inform baseline condition representations in management evaluations.

Fishery Management and Council Education and Engagement

The Ocean Noise Strategy has improved engagement and dialog on this issue within NOAA substantially, but communication remains more extensive among protected resources and protected area colleagues than among fishery habitat and management colleagues. **In parallel with further internal NOAA evaluation of this Strategy Roadmap, opportunities (webinars, briefings, brown bags etc.) could be created within Office of Habitat Conservation and Sustainable Fisheries and regional programs to promote further discussion.** These opportunities would further link NOAA's experts in fish spawning behavior, including acoustic behavior, with experts in the design and deployment of passive acoustic monitoring systems associated with consultations and permitting and experts in fishery management and in fish and invertebrate habitat protection.

Improving communication on acoustic issues within NOAA will allow the agency to engage with the fishing community in a consistent manner. Fishing industries and Fishery Management Councils (FMCs) are becoming more involved in the ocean noise discussion, especially associated with offshore use of seismic air guns in the Atlantic. In 2012, the Mid-Atlantic Fishery Management Council wrote to BOEM to oppose seismic testing on the U.S. East Coast. More recently, NSF-sponsored seismic surveys off the Mid- to South Atlantic generated significant controversy among fishery interest groups. Engagement to date showcases a need for continuing education through the FMCs. **NOAA could develop outreach materials to educate East Coast fishing communities and other stakeholders on the important role that acoustics play in the life history of many species of fishes and invertebrates, what we know about the impacts of various noise sources on these species and their habitats, where uncertainty exists, and ongoing science that NOAA is conducting or supporting to address that uncertainty.**

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The Status of Science for Assessing Noise Impacts on NOAA-Managed Species

In this Appendix, we summarize the status of the science for taxonomic groups managed by NOAA (marine mammals, fish, invertebrates, and sea turtles) as it relates to the information needed to assess the risk of noise impacts at an individual, species, and ecosystem levels. Specifically, we focus on what is known about hearing, sound use, and the effects of noise exposure for these groups. Though not intended to be comprehensive, this document is meant to serve as a reference by summarizing the status of the important components of risk assessment as they stand at the time of publication, and identifying where updates may be found in the future. The NOAA Ocean Noise Strategy (Strategy) is intended to be adaptive and will be shaped by how the science evolves.

SOUND USE, DETECTION, AND PRODUCTION

Marine Mammals

Marine mammals rely on keen hearing abilities to detect, recognize and localize biologically important sounds for navigation, predation avoidance, foraging through passive listening or active echolocation, and interspecific communication in complex, 3-dimensional marine environments (e.g. Schusterman 1981; Watkins & Wartzok 1985; Tyack 1998; Wartzok & Ketten 1999; Clark & Ellison 2004; Southall et al., 2007; Au & Hastings 2008; Richardson et al., 1995). Hearing abilities are a complex function of multiple abilities and processes including: (1) absolute threshold as a function of frequency and duration; (2) individual variation; (3) motivation; (4) masking; (5) localization; and (6) frequency and intensity discrimination (Richardson et al., 1995).

The majority of studies of hearing sensitivity, spectral analysis sensitivity, frequency and intensity discrimination, directional hearing capabilities, localization abilities, and temporary threshold shifts have been conducted using behavioral responses from a small number of captive trained animals from a limited number of odontocete and pinniped species (Richardson et al., 1995; Southall et al., 2007; Au & Hastings 2008; Houser & Moore 2014; Erbe et al., 2016), though it is also important to note the contribution of NOAA Stranding Programs to the availability of otherwise challenging species for testing. Hearing test results may vary within sex and age classes, individuals with different health and disease status, populations, and species, and can be affected by individual variation and motivation (Southall et al., 2007; Au and Hastings 2008). Recent advances in Auditory Evoked Potentials (AEPs) work is allowing expansion of frequency sensitivity studies to a wider number of individuals and greater range of species from wild populations (Houser & Moore, 2014). In species where hearing abilities are difficult to measure directly (e.g. baleen whales), anatomical modeling and knowledge of sound production can provide insights into potential hearing sensitivity (e.g., anatomical studies: Houser et al., 2001; Parks et al., 2005, ; ; Cranford & Krysl 2015 vocalizations: see reviews in Richardson et al. 1995; Wartzok & Ketten 1999; Au & Hastings 2008; taxonomy and behavioral responses to sound: Dahlheim & Ljungblad 1990; Frankel 2005; see review in Reichmuth 2007).

Based on morphological and measured or estimated hearing sensitivity comparisons, Southall et al. (2007) suggests dividing marine mammals into l hearing groups, which have been refined by NOAA (NMFS 2016), as (1) low-frequency cetaceans (all mysticetes), (2) mid-frequency cetaceans (Monodontidae, Ziphiidae, Physteridae and many Delphinidae), (3) high-frequency cetaceans (Phocoenidae, river dolphins, Kogiiadae, Cephalorhynchidae and some Lagenorhynchidae), (4) phocids, and (5) otariids.

Table A-1. Marine mammal hearing groups.

Hearing Group	Generalized Hearing Range *
Low-frequency (LF) cetaceans[+] (baleen whales)	7 Hz to 35 kHz (100 Hz to 8 kHz)**
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

***** Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).

Hearing sensitivity has been measured for a large number of species and audiograms for all studied marine mammals follow a typical mammalian U-shape with best sensitivity at the lowest points of the audiogram, a moderate slope at lower frequencies, and a strong slope at higher frequencies (Au & Hastings 2008).

In addition to hearing thresholds, frequency discrimination, localization ability, and critical ratios have been studied in a few species, as well as variables that may affect hearing thresholds (Erbe et al., 2016). Odontocetes have good frequency and intensity discrimination abilities, while frequency discrimination in otariids appears less precise than in odontocetes (Richardson et al., 1995). Odontocetes have excellent directional hearing capabilities with narrow reception beams and localization thresholds on the order of 2-4 degrees across frequencies (Au & Moore 1984). Harbor seals and otariids are known to have reasonably good directional localization abilities, but these are also less precise than those of odontocetes (Richardson et al., 1995). Across all marine mammals, critical ratios (a measure of the detectability of a tone in noise, calculated as the difference between dB level of a just detectable tone and that same spectrum of background noise) increase with increasing frequency and are low (good) by terrestrial mammal standards (Richardson et al., 1995). Across studied phocids and odontocetes, hearing thresholds increase with decreasing sound duration (below 0.1 to 1 s), similar to terrestrial mammals (Richardson et al., 1995). Animal's depth did not affect hearing sensitivity of a beluga whale, but did indicate decreased hearing sensitivity with increasing depth in a California sea lion (Ridgeway et al., 2001, reviewed in Richardson et al., 1995). Odontocetes may have learned or automatic gain control with recent evidence showing increased or decreased sensitivity in special situations (i.e., absent target and with preceding warning signal for loud signals (Nachtigall & Supin 2013, 2014), respectively) (reviewed in Houser & Moore 2014). Questions remain on the comparability of AEP and behavioral studies, and the mechanisms and impact of jawphone configuration in AEP studies (i.e. bone conduction) (summarized in Houser & Moore 2014) and there is a new American National Standards Institute group working on developing standards for odontocetes. Overall, electrical methods typically underestimate sensitivity, particularly at the lower and higher frequencies (NMFS 2016). Gender and age differences have been noted in presbycusis (age-related hearing loss) for wild *Tursiops truncatus*

(Houser and Finneran 2006; Houser et al., 2008). New hearing studies with AEPs and modeling suggest Ziphiidae and Globicephalidae hearing ranges may be different enough to distinguish them from other Delphinidae (Houser & Moore 2014).

All studied marine mammals produce complex and variable sounds which may be used in a variety of contexts including communication, navigation, courtship or territorial displays, warning signals, maintaining group structure, detecting prey, individual identification, and mother/offspring contact (Southall 2004; Edds Walton 1997; Tyack & Clark 2000; Richardson et al., 1995). These types and levels of vocalizations are summarized in the table below.

Table A-2. Summary of Marine Mammal Vocalizations.

MYSTICETES*			
Description	**Frequency**	**Source Level**	**References**
Calls, including simple calls, complex calls and impulsive calls (clicks, pulses, knocks, and grunts); Produced by all species; Function not completely understood (population-specific and geographic differences)	10 Hz– 1 kHz (some energy extending up as high as 24 kHz)	150-190 dB re 1 µPa-m	Payne & McVay 1971; Winn & Winn 1978; Ljungblad et al 1982; Payne & Payne 1985; Watkins et al. 1987; Alling & Payne 1990, Alling et al 1990; Clark 1990; Richardson et al. 1995; Payne & McVay 1997; Darling & Berube 2001; Croll et al. 2002; Oleson et al. 2003; Parks & Tyack 2005; Rankin & Barlow 2005; Au et al. 2006; McDonald et al. 2006; Oleson et al. 2007; Au & Hastings 2008; Risch et al 2013
Songs (patterned sequences of calls); Produced by blue, bowhead, fin, and humpback whales and humpback whales; For courtship or territorial displays (sex- and age-based production and variation based on behavioral state and geographic location)			
ODONTOCETES**			
Description	**Frequency**	**Source Level**	**References**
Frequency modulated tonal calls (whistles); Not produced by all species (non-whistling families: *Physteridae*, *Phocoenidae*, *Kogiadae*, and *Cephalorhynchidae*); For social communication (structure is highly variable among individuals and across species)	1-40 kHz (harmonics may extend to higher frequencies)	100-180 dB re 1 µPa-m	Caldwell & Caldwell 1965; Evans 1967; Herman and Tavolga 1980; Ford 1991; Au 1993; Richardson et al. 1995; Lammers and Au 1996; Weilgart and Whitehead 1997; Møhl et al. 2003, Zimmer et al. 2005b; Au & Hastings 2008
Broadband clicks (echolocation clicks and pulsed calls); Produced by all species; For navigation and foraging (echolocation clicks are highly directional)	<1 kHz to 150 kHz (pulsed calls); 5-130 kHz (echolocation clicks for whistling families) & 90-160 kHz (non-whistling families)	220 to 230 dB re 1 µPa-m peak to peak (whistling families); low intensity for non-whistling families, except sperm whale: 236 dB re 1 µPa-m	
PINNIPEDS			
Description	**Frequency**	**Source Level**	**References**
Vocalize in air and underwater; For aggression or attraction, particularly for territoriality and reproduction, and mother/pup contact calls; Geographic dialects described for some species	<0.2 to 10 kHz (impulsive calls to 164 kHz)	95-193 dB re 1 µPa-m	Schevill & Watkins 1965; Le Boeuf & Petrinovich 1974 Richardson et al 1995, Au & Hastings, 2008

* Detection ranges of calls are a function of source level, acoustic transmission losses (which increase with increasing call frequency), and background noise levels; in general, calls can be detected for several to hundreds of kilometers (Watkins & Schevill 1979, Watkins 1981, Clark 1983, Clark 1989, Stafford et al. 1998, Clark & Gagnon 2002, Watkins et al. 2004, Wiggins et al. 2004, Moore et al. 2006, Stafford et al. 2007, Tyack 2008).

** Detection ranges of calls are less than 1km for high-frequency clicks (Clausen et al. 2011), 1-5 km for mid-frequency clicks (Zimmer et al. 2008, Marques et al. 2009, Wiggins et al. 2012), 10-40 km for low-frequency sperm whale clicks (Barlow & Taylor 2005), and 5-10 km for whistles (Rankin et al., 2008).

Fishes

Fishes represent the largest group of vertebrate species, more than all other vertebrate groups combined. Fishes (including larval fish) may use sound for several life processes such as navigation (Staaterman & Paris, 2013), prey and predator detection, and communication. There are more than 32,000 named species of teleost fishes (see fishbase.org) and over 800 documented species of fish are known to produce sound. However, due to the sheer number and diversity of fishes, it is likely many more fish species are capable of producing sound than what is currently known (Radford et al., 2014). In addition to sound production capabilities, a fish's ability to detect sound depends on hearing sensitivity as well as special adaptations. Sensitivity to sound also varies among fishes, and many fish species have developed sensory mechanisms that enable them to detect, localize, and interpret sounds in their environment. The ability of a fish to detect and produce sound may be based on the specific anatomy and physiology of a particular species, but may also be determined to some extent by the habitats they occupy. As discussed in Chapters 2 and 3, sound is important in the aquatic environment and the habitats fish occupy may have their own acoustic characteristics. Although, when considering the effects of anthropogenic sound on fish species that NMFS currently regulates, we are concerned about those sound sources that have the ability to cause physical injury and mortality to the individual and whether or not these effects pose a risk to the population of a particular species of protected or managed species. These would be acute or limited in duration sound exposures such as those sounds generated during pile driving, seismic surveys and underwater blasts. However, chronic and continuous sound sources are also a concern, especially if they could result in a fitness consequence and decrease survival and recovery of managed and protected fish species. Thus understanding how fishes detect and respond to sound needs to be tied to ecologically relevant factors such as fish physiology and specific life stage needs, in conjunction with spatial patterns and distribution within the habitats they occupy. For a more comprehensive review of the science and information gaps regarding the effects of sound on fishes see Normandeau Associates 2012, Popper et al. 2012, Hawkins et al. 2014b, c, , Popper et al. 2014, Popper et al. 2016.

Fishes are able to detect and process sound signals via two independent, but related sensory systems: the auditory system and lateral line system. The lateral line system in fishes is essentially a mechanosensory system used to detect vibration and water flow. Therefore, it has been debated as to whether or not fish actually “hear” with the lateral line. Because of this, the two systems (auditory and lateral line) are often linked together into a single acousticolateralis system. There are good reasons to link the two, but the primary reason is that both systems possess mechanosensory hair cells, and both systems detect sound , albeit in different ways. However, for the purposes of this document, because the lateral line system is primarily for sound detection in the near field (Webb et al. 2008, Coombs et al. 2014). Therefore it will not be discussed further, and focus will be instead on the auditory system and other physical characteristics of fishes (e.g. presence of a swim bladder) that likely play larger roles in sound detection, response and sensitivity to most anthropogenic sound sources considered harmful.

Auditory System: The bodies of fish have approximately the same density as water, so sound pressure can pass through their bodies, with their body moving in concert with the sound pressure wave. Fish can detect both particle motion and pressure components of a sound wave. According to Popper and Fay (2010), the most common mode of hearing in fishes involves sensitivity to acoustic particle motion via direct inertial stimulation of the otoliths found in the inner ears of fishes. Otoliths are comprised of calcium carbonate, and the shape and size of otoliths can vary among species. These otoliths are denser than water and the fish's body and, as a result, “move with a different amplitude and phase” than the fish’s body (Ramcharitar et al. 2006). It is the relative motion between the otolith and the sensory cells located on the epithelium of the inner ear that results in bending of the cilia on the hair cells (Hawkins and Popper 2016 pers. comm). This differential movement between the otoliths and hair cells is interpreted by the fish’s brain as sound (for more details on auditory system of fishes visit: http://www.popperlab.umd.edu/background/index.htm).

Fish with Swim Bladders: Differences in sensitivity (both hearing and physical) to acoustic pressure are also the result of the presence and type of swim bladder, as well as proximity and linkage of the swim bladder to the ear (Popper et al. 2003, Ramcharitar et al. 2006, Braun & Grande 2008, Deng et al. 2011) and in some cases, the structure of the inner itself (Deng et al. 2011). When a sound pressure wave passing through the fish’s body causes the swim bladder to move, this movement is transmitted to, and stimulates, the inner ear (described above).

Fishes with swim bladders are likely more susceptible to physical injury from underwater sound exposure than are fishes that lack swim bladders. As sound pressure waves pass through the a fish's body the swim bladder routinely expands and contracts with the fluctuating sound pressures. The air within the swim bladder is a much lower density than that of water and the fish's body , thus the air (and swim bladder) can easily be compressed by sound pressure waves traveling through the fish's body. This movement of the swim bladder can result in injury. This will be discussed further in the *physical effects* section.

There are two types of swim bladders, open vs closed (i.e., physostomous and physoclistous). This as well as the state of buoyancy may be a factor that influences the degree of injury they sustain from exposure to high sound pressure levels. For example, a deflated swim bladder could put the fish at a lower risk of injury from the sound exposure compared to a fish with an inflated swim bladder (e.g., Halvorsen et al., 2012, 2013.)..

Fish without swim bladders: In general, fish species lacking a swim bladder (e.g., sharks, flatfish and some tunas), or those that have small or reduced swim bladders (such as many benthic species, including some flatfish), tend to have relatively poor auditory sensitivity, and generally cannot hear sounds at frequencies above 1 kHz. However, these species (such as plaice and dab) are capable of detecting and responding to water movement/vibration in the near field and acoustic particle motion in the far field (Sand & Bleckmann 2008, Rogers and Zeddies 2008). Limited research comparing susceptibility to physical injury between fishes with and without swim bladders indicates fishes without swim bladders may be less at risk of sustaining harm from exposure to high sound pressure levels than those that possess swim bladders (Goertner et al. 1994, Halvorsen et al. 2012a, b).

Hearing Specializations: Fishes with anatomical specializations between the swim bladder (or other gas bubble) and ear generally have lower thresholds and wider hearing bandwidths than species without such specializations. Fishes that possess connections or a close proximity between the inner ear and the swim bladder may have greater ability to detect, and therefore respond to, sound pressure. This is because the sound pressure waves cause the gas-filled spaces to vibrate, generating particle motion that stimulates the inner ear. Thus, the degree of hearing sensitivity can depend on how close the swim bladder is to the ear and how far the signal has to travel. For example, fishes belonging to clupeiform species (e.g., shad, herring, sardines, and alewives) have a pair of elongated gas ducts ending in "bullae" that extend from the swim bladder, go through the skull, and directly contact the inner ear. (Fay and Edds-Walton 2008). The presence of a bubble of compressible gas in the bullae located within close proximity to the inner ears enhances stimulation of the ear, which increases hearing sensitivity (DOSITS, 2010). Although, these hearing specializations are rather unique, and many fishes do not possess such specializations.

There are many other fishes that possess swim bladders, but with no special adaptations (Coombs and Popper 1979, Ramcharitar et al. 2006). These fish often do not have a high degree of hearing sensitivity compared to those described above. For example, Atlantic salmon (*Salmo salar*) have poor hearing sensitivity (Hawkins & Johnstone 1978, 2006). These fish are only capable of detecting low frequency tones (below 380 Hz) and particle motion rather than sound pressure.

Invertebrates

The use of sound in aquatic invertebrates has not been as widely studied as other marine animals. There remains much to be learned about invertebrate sound detection along with the potential physical and behavioral effects from sound exposure. However, we know that some species of invertebrates (e.g., larval coral, squid, octopuses and oysters), may use sound to obtain information about their environment, and can physically orient themselves based upon the sound characteristics of the areas they occupy (Cohen 1955, Budelmann 1992, Vermeij et al 2010, Kaifu et al. 2008, Simpson et al. 2011, Normandeau Associates 2012, Hawkins et al. 2014b). Separately, some species of marine invertebrates are known to be capable of producing sounds for biological needs such as courtship, foraging, and protection from predators. One of the better known examples of marine invertebrate sound production is found in species of pistol or snapping shrimp (Verslius et al. 2000).

Although our knowledge of invertebrate "hearing" is limited, there is evidence that at least some invertebrates are able to detect vibrations and movements associated with sound production and are sensitive to low frequency sounds (Breithaupt 2002; Lovell et al., 2006; Mooney et al., 2010, 2012). Whether or not they are sensitive to sound pressure in a similar manner as other animals, like fishes, is not clear. Available data suggest that they are capable of detecting vibrations, but do not appear capable of detecting pressure fluctuations. It is currently thought that sound detection in invertebrates occurs through two types of receptors. The first is through sensory organs such as statocysts (or otocysts). Statocysts are fluid-filled structures in many invertebrates that contain sensory cilia and help maintain balance and position (i.e., equilibrium). Although there are some differences, statocysts are similar to the otoliths in fish. Because they resemble fish otoliths, it has been suggested that they may be able to detect particle motion or vibration associated with sound (Cohen 1955; Budelmann 1992, Kaifu et al. 2008). The second mechanism is through the water flow detectors or sensory hairs that aquatic invertebrates possess. Flow detectors are typically comprised of sensory cilia on the body surface of invertebrates (found on most marine crustaceans), or are hair/fan-like projections. Flow detectors are thought to be capable of detecting water-borne vibrations (Laverack 1981; Budelman & Bleckman 1988; Popper et al., 2001).

Other invertebrates are capable of detecting and responding to acoustic cues, observed by directional movement towards and settlement on substrate, or orienting themselves within their environments. A recent study conducted in North Carolina focused on Eastern oyster larvae (*Crassostrea virginica*) and use of sound to detect suitable substrate for settlement (Lillis et al., 2013). Therefore, habitat-specific sound characteristics within marine communities may represent an important settlement and habitat selection cue for estuarine invertebrates, and could help drive settlement and recruitment patterns.

Similarly, Vermeij et al. (2010) recently conducted a study focused on invertebrate sound detection and response for a species of reef coral (*Montastraea faveolata*). The researchers studied free-swimming larvae of tropical corals and were able to demonstrate that coral larvae are capable of detecting reef sounds and respond to these sounds in a directional manner through movement towards the sound source. The researchers suggest that if, like settlement-stage reef fish and crustaceans, coral larvae use reef noise as a cue for orientation and colonization, then the potential management of marine noise pollution in coral reef communities warrants more attention.

Sea Turtles

The biological significance of hearing in sea turtles remains largely unstudied, but it seems likely that they use sound for navigation, to locate prey, to avoid predators, and for general environmental awareness. Electrophysiological and behavioral studies of hearing have demonstrated that green, loggerhead, Kemp's ridley, leatherback, and hawksbill sea turtles detect low frequency acoustic and vibratory stimuli underwater and in air <2000 Hz (Bartol et al., 1999; Dow Piniak 2012; Dow Piniak et al., 2012a; Dow Piniak et al., 2012b; Lavender et al., 2014; Martin et al., 2012; Ridgway et al., 1969). Hearing has not been measured in olive ridley or flatback sea turtles, and behavioral audiograms are only available for loggerhead sea turtles (Lavender et al., 2012; Martin et al., 2012). Sea turtles do not appear to use sound for communication. Leatherback sea turtles have been recorded making low-frequency sighs or grunt-like sounds up to 1,200 Hz (maximum energy from 300-500 Hz) while nesting, however these sounds appear to be associated with respiration (Mrosovsky 1972; Cook & Forest 2005).

IMPACTS OF NOISE

The effects of exposure to sound on marine animals may include physical injury, physiological effects (such as adverse stress responses), behavioral modifications, or masking of important sounds (e.g., those used in communication, navigation or detection of predators or prey). Disturbances from noise may be relatively short-term and spatially limited, resulting in more obvious direct effects such as easily detectable behavioral changes, or they may be more subtle, such as rises in background noise spanning months and large areas, which may lead to chronic effects that are more difficult to detect, such as a reduced ability to detect prey. The nature and scope of the likely effects from noise disturbances are dependent upon the context of the exposures and the details of any acoustic habitat impacts; however, it is important to understand that these impacts can, either individually or in combination, effect the reproduction and survival of individual marine animals, which can in turn lead to effects on populations. Additionally, the cumulative impacts from other stressors in combination with noise can have further negative energetic burdens or impacts on health that contribute to decreases in individual fitness.

Marine Mammals

Physical Effects: Exposure to noise has the potential to affect the inner ear and hearing. Noise-induced threshold shifts are defined as increases in the threshold of audibility (i.e., the sound has to be louder to be detected) of the ear at a certain frequency or range of frequencies (ANSI 1995; Yost 2000), i.e., a loss in hearing sensitivity. Threshold shifts can be temporary (TTS) or permanent (PTS) and are typically expressed in decibels (dB). Threshold shifts result from a variety of mechanical (via physical damage) and metabolic (via inner ear hair cell metabolism, such as energy production, protein synthesis, and ion transport) processes within the auditory system. The mammalian cochlea is believed to be highly conserved between terrestrial and marine mammals (Wartzok & Ketten 1999; Ketten 2000). Thus, as with other mammals, noise-induced hearing loss occurs at lower thresholds for impulsive versus non-impulsive sound sources.[8] Additionally, it is known that not only level of exposure but also duration of exposure plays a critical role in determining the amount of threshold shift and subsequent recovery.

Currently, TTS data only exist for four species of cetaceans (bottlenose dolphins, belugas, harbor porpoises, and Yangtze finless porpoises) and three species of pinnipeds (Northern elephant seal, harbor seal, and California sea lion) exposed to a limited number of sound sources (i.e., mostly tones and octave-band noise) in laboratory settings (Finneran 2015). In general, harbor seals (Kastak et al., 2005; Kastelein et al., 2012a) and harbor porpoises (Lucke et al., 2009; Kastelein et al., 2012b) have a lower TTS onset than other measured pinniped or cetacean species. Additionally, the existing marine mammal TTS data come from a limited number of individuals within these species. There are no data available on noise-induced hearing loss for mysticetes, which is not surprising since there are no direct measurements of hearing for any of these species. PTS data (unexpected) only exists for a single harbor

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[8] Impulsive: Sound sources that produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). They can occur in repetition or as a single event. Non-impulsive: Sound sources that produce sounds that can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high peak sound pressure with rapid rise time that impulsive sounds do.

seal (Kastak et al., 2008). For a summary of marine mammal noise-induced hearing loss studies, see the NMFS Acoustic Guidance (NMFS 2016).

For explosions, there is concern with not only the effects from exposure to the acoustic waves generated but also from exposure to shock wave pulses. These pulses typically have short durations and high peak pressures that may damage internal organs (see Urick 1983; Ross 1987). Air-filled body cavities, such as lungs or the gastrointestinal tract, are particularly susceptible to injury from these shock wave pulses as they pass through the boundary of two different media (i.e., from water to air-filled cavities; Yelverton et al., 1973; Goertner 1982). Bubble pulses (series of pressure pulses following a shock wave pulse generated close to explosions) are also capable of inducing physical damage (Urick 1983). Animals are most susceptible to physical injury from explosives when they are the same depth as the explosive charge (Goertner 1982). There have been incidents where marine mammals were exposed to explosives either intentionally or by accident (reviewed in Danil & St. Leger 2011).

Finally, gas bubble lesions and fat emboli (similar to those associated with human decompression sickness) have been reported in beaked whale species that stranded coincident (in space and time) with naval activities involving the use of mid-frequency sonar (Jepson et al., 2003; Fernández et al., 2005; Fernández et al., 2012). Currently, these lesions/emboli are believed to result from behavioral responses to sonar exposure (e.g., change in dive profile as a result of an avoidance reaction), rather than direct physical effects associated with sonar exposure (Cox et al., 2006; Tyack et al., 2006; Zimmer and Tyack 2007).

Behavioral Effects: Exposure to anthropogenic sound can result in a multitude of behavioral effects, ranging from no or minor effects (such as minor or brief avoidance or changes in vocalizations), to those being more potentially severe or sustained (e.g., abandonment of higher quality habitat), and even, in certain circumstances, those that can combine with physiological effects or result in secondary responses that lead to stranding and death. Assessing the severity of behavioral effects of anthropogenic sound exposure on marine mammals presents a set of unique challenges, which arise from the inherent complexity of behavioral responses. Responses can depend on numerous factors, including intrinsic, natural extrinsic (e.g., ice cover, prey distribution), or anthropogenic, as well as the interplay among factors (Archer et al., 2010). Behavioral reactions can vary not only among individuals but also within an individual, depending on previous experience with a sound source, hearing sensitivity, sex, age, reproductive status, geographic location, season, health or disease status, social behavior, or context (Ellison et al., 2012). Responses can also vary depending on characteristics associated with the sound source (e.g., whether it is moving or stationary, number of sound sources, distance from the sound source) and the potential of source and individuals co-occurring temporally and spatially (Richardson et al., 1995; NRC 2003; Wartzok et al., 2004; NRC 2005; Southall et al., 2007).

Not all behavioral responses have the same consequences. Those that have the potential to affect vital rates or have fitness consequences (effects on growth, reproduction, and survival) can lead to potential population effects and are deemed to have more serious impacts (NRC 2005). However, basic baseline behavioral assessments (e.g., how an animal normally behaves without anthropogenic sound exposure within various contexts or how detected behaviors relate to the individual in a broader context) are also often lacking in marine mammal acoustical studies, which makes it difficult to assess severity of changes associated with anthropogenic sound exposure (Tyack 2009). Furthermore, some species have been identified as being particularly sensitive to sound exposure (i.e., demonstrate behavioral harassments at lower received levels than other species), namely beaked whale species and harbor porpoises (e.g., Southall et al., 2007; Olesiuk et al., 2002; Tyack et al., 2011).

Most data available on marine mammal behavioral responses to anthropogenic sound, especially for mysticetes, comes from exposure to seismic or drilling activities (behavioral data reviewed in Richardson et al., 1995; Southall et al., 2007; Nowacek et al., 2007; OSPAR 2009). For odontocetes, most behavioral data come from exposure to acoustic deterrent or harassment devices (ADDs or AHDs) and recent data on exposure to mid-frequency tactical sonars. Overall, the behavioral responses of pinnipeds to underwater sound sources have been the least studied. Additionally, there is an overall paucity of data on behavioral responses of marine mammals exposed to pile driving activities (both impact and vibratory), especially associated with smaller nearshore projects (i.e., more data available for a limited number of species exposed to pile driving associated with wind farm development in Europe). It is also important to note, that unlike marine mammal TTS studies that are typically published in peer-reviewed journals, marine mammal behavioral data are found in a variety of published and unpublished documents (e.g., monitoring reports, technical reports), with varying levels of quality.

Masking and Acoustic Habitat Impacts: Masking is the interference in the detection, recognition or discrimination of an acoustic signal (e.g., intraspecific communication and social interactions, prey detection, predator avoidance, and navigation) by the presence of another (e.g., natural (snapping shrimp, wind, waves, precipitation) or anthropogenic noise (shipping, sonar, exploration)(Houser & Moore 2014). The ability of a noise source to mask biologically important sounds depends on the noise source characteristics and the important signal characteristics (SNR, temporal variability, direction) as a function of each other, an animal's hearing abilities (sensitivity, frequency range, critical ratios, frequency discrimination, directional discrimination, age or TTS hearing loss) , and ambient noise and propagation conditions (Erbe et al., 2016). Studies of a few captive trained bottlenose dolphins, beluga whales, and several pinniped species suggest, (1) as for other mammals, increasing critical ratio (i.e. wider filter width) trends with increasing frequency, (2) species-specific differences exist in critical ratios and hence the ability to cope with masking noises (but note low sample sizes), (3) directional hearing and localization abilities are strong beyond 4-5 degrees, and (4) frequency discrimination abilities are frequency dependent and better than those of humans (on the order of 0.01 to 8 kHz between 1 and 80 kHz) (Richardson et al., 1995). Masking can be reduced in situations where the signal and noise come from different directions (Richardson et al., 1995), if mammals compensate (e.g., Lombard effect, frequency shifts, multiple looks, extended durations/modulations, spatial release) (Erbe in Houser & Moore 2014) , or through amplitude modulation of the signal (Branstetter, in Houser & Moore 2014).

Fishes

*Physical Effects—*Auditory tissue damage can occur in fishes from exposure to high intensity sounds. Injury may also occur for fishes exposed to high levels or continuous sound, manifested as a loss of hair cells, located on the epithelium of the inner ear (Popper and Hastings 2009). These hair cells are capable of sustaining injury or damage that may result in a temporary decrease in hearing sensitivity or temporary threshold shifts (TTS). Exposure to loud sounds for a few minutes or hours has been shown to cause TTS is in fishes. TTS is considered a non-injurious temporary reduction in hearing sensitivity. However, this type of noise-induced hearing loss in fishes is generally considered recoverable, as fish possess the ability to regenerate damaged hair cells (Smith et al., 2006), unlike mammals. Permanent hearing loss has not been documented in fishes. A TTS may last several minutes to several weeks and the amount of hearing loss may be related to the intensity and duration (including multiple exposures) of the sound source compared to the hearing threshold at the same frequencies.

It should be noted, however, several studies conducted that demonstrate TTS in fishes after exposure to sound did not correlate the TTS with actual ear tissue damage (Scholik and Yan 2001, Popper et al.

2005, Popper et al . 2007, Song et al. 2008). Some of these studies did indicate, however, that TTS may persist and last for several days past exposure. Therefore, an important consideration in examining the effects of TTS in fishes is determining what level of hearing loss has significant implications for behavior and any associated fitness consequences, such as preventing individuals from detecting biologically relevant signals.

Other studies have been conducted regarding structural damage on fish inner ears, although these studies did not correlate damage to TTS (e.g. Enger 1981, Hastings et al. 1996, McCauley et al., 2003). As with TTS, the degree of injury and duration of time it takes for a fish to heal these injuries may affect behavior or other necessary life functions.

Fish may be injured or killed when exposed to high levels of underwater sound, such as those generated by impulsive sound sources from pile driving or underwater explosions. Pathologies of fishes associated with very high sound level exposure and drastic changes in pressure are collectively known as *barotraumas*. As described previously, sound pressure waves can pass through a fish's body and cause the swim bladder to routinely expand and contract with the fluctuating sound pressures. At exposure to high sound pressure levels, such as with pile driving, the swim bladder may rapidly and repeatedly expand and contract, and pound against the internal organs. This pneumatic pounding may result in hemorrhage and rupture of blood vessels and internal organs, including the swim bladder, liver and kidneys. External damage has also been documented, evident with loss of scales, hematomas in the eyes, base of fins, etc. (Yelverton et al. 1975, Wiley et al. 1981, Linton et al. 1985, , Godard et al. 2008, Carlson et al. 2011, Halvorsen et al. 2012a, Halvorsen et al. 2012b, Casper et al. 2012). Fishes can survive and recover from some injuries, but in other cases, death can be instantaneous, occur within minutes after exposure, or occur several days later. .

In addition to the presence of a swim bladder, the level or degree of severity of injury a fish sustains may also be dependent upon the amount of air (state of buoyancy) in the swim bladder during sound exposure (Govoni et al. 2003, Halvorsen 2012a, Stephenson et al. 2010, Carlson 2012) as well as the physiological state of fish at exposure. For example, a deflated swim bladder (negatively buoyant) could put the fish at a lower risk of injury from the sound pressure exposure compared to a fish with an inflated swim bladder (positively buoyant).

Beyond effects associated with changes in pressure, more research is needed to understand the potential of injury from sources with high levels of particle motion, like various impulsive sources (Popper et al. 2014). Finally, additional physiological effects to fishes from exposure to human-made sound were increases in stress hormones or changes to other biochemical stress indicators (e.g., Sverdrup et al. 1994, Santulli et al. 1999, Wysocki et al., 2006, Nichols et al., 2015).

Behavioral Effects: Underwater sounds have been shown to alter the behavior of fishes (see review by Hastings & Popper 2005; Hawkins et al.2012; Popper et al., 2014), although there is significant variation between species. Observed behavioral changes from exposure to human-made sound may include startle responses, changes in swimming directions and speeds, increased group cohesion and bottom diving (Engas et al., 1995, Wardle et al., 2001, Mitson & Knudsen 2003, Boeger et al., 2006, Sand et al., 2008, Neo et al. 2014) "alarm," detected by Fewtrell et al. (2003)and Fewtrell and MacCauley (2012). The startle response in fishes is a quick burst of swimming that may be involved in avoidance of predators (Popper 1997). A fish that exhibits a startle response or some of the other behaviors may not necessarily be injured, but is exhibiting behavior that suggests it perceives a stimulus indicating potential danger in its immediate environment. Therefore, these type of responses likely do not have a fitness consequence for the individual unless the reaction increases susceptibility to predation or some other negative effect. However, fish do not exhibit a startle response or some of the other behaviors every time they experience a strong hydroacoustic stimulus.

Other potential changes include reduced predator awareness and reduced feeding (Voellmy et al. 2014, Simpson et al. 2015), or changes in in distribution in the water column or schooling behavior (e.g., Skalski et al., 1992, Feist et al., 1992, Engås et al., 1996, Engås & Løkkeborg 2002, Slotte et al., 2004The potential for adverse behavioral effects will depend on a number of factors, including the sensitivity to sound, the type and duration of the sound, as well as life stages of fish present in the areas affected by underwater sound.

It is worth a note of caution to say that most data available on behavioral responses of fishes to anthropogenic sound has been obtained through controlled, laboratory studies. In other cases behavioral studies have been conducted in the field, albeit with caged fish. Hawkins and Popper (2014) and Hawkins et al. (2014a) have demonstrated that caged fish do not show normal behavioral responses which makes it difficult extrapolating caged fish behavior to wild, unconfined fishes. It is also important to note, that some of the information regarding fish behavior while exposed to anthropogenic sounds has been obtained from unpublished documents such as monitoring reports, grey literature or other non-peer reviewed documents with varying degrees of quality.

Masking: The frequency, received level, and duration of the sound exposure determine the potential degree of auditory masking. Similar to hearing loss, the greater the degree of masking, the smaller the area becomes within which an animal can detect biologically relevant sounds such as those required to attract mates, avoid predators or find prey (Slabbekoorn et al. 2010, Dooling et al. 2015). Because the ability to detect and process sound may be important for fish survival, anything that may significantly prevent or affect the ability of fish to detect, process or otherwise recognize a biologically/ecologically relevant sound could decrease chances of survival. For example, some studies on anthropogenic sound effects on fishes have shown that the temporal pattern of fish vocalizations (e.g., sciaenids and gobies) may be altered (Parsons et al., 2009) when fish are exposed to sound-masking. This may indicate fish are able to react to noisy environments by exploiting “quiet windows” (Lugli 2003, 2009) or are moving from affected areas and congregating in areas less disturbed by nuisance sound sources. In some cases, vocal compensations occur, such as increases in the number of individuals vocalizing in the area, or increases in the pulse/sound rates produced (Picciulin et al., 2012). Vocal compensations could have an energetic cost to the individual which may lead to a fitness consequence such as affecting their reproductive success or increase detection by predators (Bonacito et al., 2001; Amorin et al., 2002).

Invertebrates

Anthropogenic noise in the marine environment may cause physical damage to invertebrates through damaging the hair cells in their statocysts. Researchers in Spain (Andre et al., 2011, Solé et al. 2013) showed acoustic trauma to squid and octopuses exposed to the high-intensity, low-frequency sounds (50 – 400 Hz).. Exposure to these sounds caused hair cell damage in the statocyst which, over time, became more severe resulting in the appearance of lesions several hours after exposure to the sound source. The research indicates that continuous sound exposure may cause severe acoustic trauma to these species. Anthropogenic sound exposure may also affect development of some invertebrate species and increase mortality rates for certain lifestages (Nedelec et al. 2014). Very little is known about invertebrate behavior associated with anthropogenic sound exposure. However, recent research indicates marine invertebrates may respond to sound in several ways such as with directional movement towards biologically relevant sounds (Vermeij et al. 2010, Simpson et al. 2011) or through "inking, jetting and raid colorations changes," which are escape responses demonstrated with cuttlefish by Samson et al. (2014). This same study also found that cuttlefish were able to habituate to repeated sound levels over a 30 minute period. It is not currently known whether or not masking occurs in invertebrates. However, masking could be considered a potential effect of anthropogenic sound on marine invertebrates if the sound prevents the detection of low-frequency vibrations or other biologically relevant sounds.

Sea Turtles

We understand very little about the impacts of noise on sea turtles. No research has been conducted on the physiological effects of noise on sea turtles. Very little data exist on the behavioral responses of sea turtles to noise. However, of the studies available, many concluded that sea turtles change their behavior in some way in response to noise. Most sea turtle behavioral response studies have examined the response of sea turtles to sounds produced by seismic airguns (Moein et al., 1995, observed avoidance and then habitutation; O'Hara & Wilcox, 1990, observed some turtles responding, but others not responding; McCauley et al., 2000 observed increased swimming and erratic behavior in response to approaching airguns; Weir 2007 observed no significant change in sea turtles visually sighted near active and inactive airgun arrays; and DeRuiter and Doukara, 2012, observed diving response to airguns). One additional study observed that green turtles were more likely to avoid approaching high speed vessels, rather than those travelling at low or moderate speeds, however, the authors did not measure source or received levels of sound (Hazel et al., 2007). To date, all studies have focused on evaluating the behavioral responses of loggerhead or green sea turtles.

No information exists on the impacts of masking important biological cues or deterioration of acoustic habitat for sea turtles. We do not understand how noise impacts populations, survivorship or fecundity, nor do we understand the cumulative impacts of noise on individuals or populations when combined with other stresses (bycatch, climate change, etc.).

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Presence, Abundance, Distribution, Density, Habitat Use and Population Trends

Many entities conduct surveys and research on marine taxa that can contribute to our broader understanding of the spatial and temporal distribution and density of marine mammals within their ranges. NOAA's mandate includes the responsibility to collect the data necessary to support broad-scale and long-term species or stock assessments of protected species. While other datasets provide very useful information (addressed below in each taxa section), a look at NOAA's data for marine mammals and ESA-listed species provides the best overview of the status of the comprehensive large-scale survey data that can be used (if collected with adequate frequency) to estimate abundance and population trends, as well as density and distribution. Additionally, in response to the requirements of the Government Performance and Results Act (GPRA), NOAA developed a method for ranking the adequacy of its stock assessments based on factors such as the frequency of surveys, the quality of the abundance estimate, available information on stock structure, and our understanding of anthropogenic impacts (Table B-1). Using these taxa-specific factor rankings, NOAA further established that an overall Tier 2 ranking is necessary for an assessment to be considered "adequate," and identified how that could be achieved (see Tables B-4 to B-7 at the end of this Appendix). While broadly valuable, note that GPRA ranks are qualitative and can be somewhat subjective, and it is difficult to draw conclusions across years when stocks or species are split. NOAA also tracks the population trends of ESA-listed species (Table B-2).

Additionally, the ESA provides for the designation of Critical Habitat and the development of Recovery Plans for listed species. Critical habitat designations delineate areas of particular importance for ESA-listed species and explicitly describe the "primary constituent elements" of the designated Critical Habit, or what makes that habitat important. Recovery Plans, which are used to promote the conservation of the species and identify the thresholds for de-listing, include details of what is known about the biology of the species, specific threats, and a recovery strategy that lays out specific conservation measures.

Below, we summarize the availability of NOAA data using the GPRA information, as well as the availability of ESA Recovery Plans and Critical Habitat designations (Table B-3). All information related to ESA-listed species, including links to all Recovery Plans and designated Critical habitat, may be found here: http://www.nmfs.noaa.gov/pr/species/esa/listed.htm. Where available, we highlight in the next sections the other types of taxa-specific data available to characterize presence, abundance, density, distribution, habitat use, and population trends for the different taxa.

Additional Information: Marine Mammals

NOAA's stock assessment reports for marine mammals, which may be found at (http://www.nmfs.noaa.gov/pr/sars/species.htm), provide estimated abundance and population trends for all marine mammal species, as well as a summary of other important information such as the range of the species and anthropogenic threats. Beyond what is noted above, about 47% of the stocks have either never had an assessment conducted, or the last one was over 10 years ago.

When robust survey data are available (from NOAA or otherwise), they may also be used, either alone or in combination with measures of environmental data known to be correlated with marine mammal presence to provide spatio-temporally explicit marine mammal density and distribution predictions. OBIS-SEAMAP (http://seamap.env.duke.edu) houses a tremendous amount of marine mammal observation data, in the form of both raw data and processed density and habitat suitability models. In

NOAA's CetMap website (http://cetsound.noaa.gov), available data and density models are presented, characterized, and provided in a manner that allows users to quickly determine what types of data are available within a region for a particular stock. The CetMap website also includes the description and results of an effort to identify "biologically important areas" for cetaceans, e.g., areas where cetaceans are known to concentrate for reproductive behaviors, feeding, or migration, or areas with small and resident populations of cetaceans. Generally speaking, the highest quality habitat-based density estimates are only available for a subset of species and only for the summer months.

Additional Information: Fishes

NOAA works with the regional fishery management councils to identify the "Essential Fish Habitat (EFH)" for every life stage of each federally managed species using the best available scientific information. Essential fish habitat includes all types of aquatic habitat—wetlands, coral reefs, seagrasses, rivers—where fish spawn, breed, feed, or grow to maturity. Essential fish habitat has been described for approximately 1,000 managed species to date. NOAA and the councils also identified more than 100 "habitat areas of particular concern" or HAPCs. These are considered high priority areas for conservation, management, or research because they are rare, sensitive, stressed by development, or important to ecosystem function. NOAA has created an "EFH Mapper," which is a one-stop tool for viewing the spatial representations of fish species, their life-stages and important habitats (http://www.habitat.noaa.gov/protection/efh/habitatmapper.html).

Finally, NOAA Fisheries provides stock assessment advice in support of fishery status determinations, setting annual catch limits, and management of sustainable fisheries. Information, including the percentage of stocks with adequate assessments based on the Fish Stock Sustainability Index (FSSI; 230 stocks selected for their importance to commercial and recreational fisheries), is tracked on a quarterly and annual basis in order to measure performance of the national stock assessment program. Adequate assessments are conducted using production models or, better, have been validated by a regional review, and are no more than five years old. This information is available here: (http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/).

Table B-1. Summary of overall 2013 Tier ratings of assessment quality for marine mammal stocks and ESA-listed species (fish, invertebrates, and sea turtles). "3" is best, "2" is adequate, "1" and "0" are progressively worse. Tables B-4 to B-7 describe how the stocks are ranked.

ALL MARINE MAMMALS						
Tier Levels	**SWFSC**	**NWFSC**	**PIFSC**	**AFSC**	**NEFSC**	**SEFSC**
0	6	0	28	0	0	0
1	19	0	92	32	16	83
2	14	1	5	19	8	7
3	0	0	0	0	1	0
Total # of Stocks	39	1	125	52	25	90
% with overall rank >= Tier 2 (adequate)	**36%**	**100%**	**4%**	**37%**	**36%**	**8%**
ESA-LISTED FISH						
Tier Levels	**SWFSC**	**NWFSC**	**PIFSC**	**AFSC***	**NEFSC**	**SEFSC**
0	0	0			0	0
1	11	4			8	14
2	0	18			1	1
3	0	0			1	0
Total # of Species	11	22			10	15
% with overall rank >= Tier 2 (adequate)	**0%**	**82%**			**20%**	**7%**
ESA-LISTED SEA TURTLES						
Tier Levels	**SWFSC**	**NWFSC**	**PIFSC**	**AFSC***	**NEFSC**	**SEFSC**
0	1		0			0
1	2		2			2
2	0		0			0
3	0		0			0
Total # of Species	3		2			2
% with overall rank >= Tier 2 (adequate)	**0%**		**0%**			**0%**
ESA-LISTED MARINE INVERTEBRATES						
Tier Levels	**SWFSC**	**NWFSC**	**PIFSC**	**AFSC***	**NEFSC**	**SEFSC**
0	0					0
1	2					2
2	0					0
3	0					0
Total # of Species*	2					2
% with overall rank >= Tier 2 (adequate)	**0%**					**0%**
*Note that 20 new coral species were listed in 2014						

Table B-2. Trends of numbers of populations/stocks of indicated taxa ("mixed" indicates when there are multiple populations of same species and some are increasing and some are decreasing).

	Number of Species with Indicated Population Trends					
	increasing	stable	mixed	declining	unknown	unranked
ESA-listed Marine Mammals	7	3	4	1	13	3
ESA-listed Fish	2	16	4	1	14	5
ESA-listed Sea Turtles	2	0	5	0	1	0
ESA-listed Invertebrates	0	0	0	2	2	0

Table B-3. Number of ESA-listed species or Distinct Population Segments for each taxa along with number of final critical habitat designations and recovery plans.

	# ESA-listed species or DPSs	# species critical habitat designated	# recovery plans finalized
Marine Mammals	31	6	10
Fish	53	10	16
Sea Turtles	16	5	11
Invertebrates	24	4	1

Table B-4. Factors used in evaluating marine mammal stock assessments. Note that ESA-listed or MMPA depleted species must be ranked 3 in all categories to be considered Tier 2 overall (adequate), whereas non-listed or depleted marine mammals are considered overall Tier 2 when ranked at least 2 in all categories.

Category/ Level for Tier Rating	Description
Stock Identification	
0	No information (qualitative or otherwise) available
1	Structure inferred from analyses undertaken for other purposes (e.g., distribution, differences in trends, differences in life history)
2	Structure inferred from an analysis specifically aimed at investigating population differentiation (e.g., pollutants, stable isotopes, genetics, tagging)
3	Structure inferred from an integrative analysis of at least two lines of evidence of the type listed under Level 2
4	Estimates of dispersal rate that include estimates of uncertainty
Abundance	
0	No information (qualitative or otherwise) available
1	Minimum count, abundance estimate, or index count
2	Unbiased estimate of abundance (CV≥30%)
3	Unbiased estimate of abundance (CV<30%) with seasonally OR geographically-explicit density
4	Seasonal and geographic-specific density estimates
Anthropogenic Impacts	
0	No information (qualitative or otherwise) available
1	Qualitative evidence of anthropogenic impacts
2	Minimum estimate of anthropogenic impacts
3	Unbiased estimate of anthropogenic impacts (CV≥30%)
4	Precise estimate of anthropogenic impacts (CV<30%) OR no evidence of human-induced mortality
Assessment Quality	
0	No assessments conducted
1	Assessment with minimum abundance or index only
2	Assessment using simple deterministic models with defaults or proxies
3	Assessment using more advanced deterministic models without defaults or proxies
4	Assessment using species-specific sophisticated models, such as stochastic models, depletion models, or projection models (e.g., population viability analysis, PVA)
Assessment Frequency	
0	No assessment conducted
1	Most recent assessment is ≥10 years old
2	Most recent assessment is 6-9 years old
3	Most recent assessment is 2-5 years old
4	Most recent assessment is ≤ 1 year old

Table B-5. Factors used in evaluating ESA-listed fish species assessments. Note that a species must be ranked 3 in all categories to be considered Tier 2 overall (adequate).

Categor	Short Description	Long Description ("metadata")
Stock Identification		
0	No information (qualitative or otherwise) available	No information (qualitative or otherwise) available.
1	Structure inferred from analyses undertaken for other purposes (e.g., distribution, differences in trends, differences in life history)	Structure inferred from analyses undertaken for other purposes (e.g., distribution, differences in trends, differences in life history).
2	Structure inferred from an analysis specifically aimed at investigating population differentiation (e.g., pollutants, stable isotopes, genetics, tagging)	Structure inferred from an analysis specifically aimed at investigating population differentiation (e.g., pollutants, stable isotopes, genetics, tagging).
3	Structure inferred from an integrative analysis of at least two lines of evidence of the type listed under Level 2	Structure inferred from an integrative analysis of at least two lines of evidence of the type listed under Level 2.
4	Estimates of dispersal rate that include estimates of uncertainty	Estimates of dispersal rate that include estimates of uncertainty.
Abundance		
0	None	No abundance data.
1	Fishery CPUE or imprecise survey with size composition	Relative abundance index from fishery CPUE or an imprecise, infrequent survey. Another Level 1 situation would be a single survey from which an estimate of absolute abundance has been made. At this low level of information, there will only be a limited ability to track changes in stock abundance because of uncertainties in the calibration of the index, or a high level of noise in the data relative to the magnitude of the expected changes in stock abundance.
2	Precise, frequent survey with age composition	Precise, frequent surveys with age composition will provide more accurate tracking of changes in stock abundance and the associated age composition date will enable better estimation of historical and current levels of recruitment.
3	Survey with estimates of q	Research surveys with known or estimated catchability, acoustic surveys with known or estimated target strengths, and statistically designed tagging studies can provide estimates of absolute abundance. This is especially valuable when the time series of the survey is so short that no trend is detectable.
4	Habitat-specific survey	Habitat-specific surveys refine the concept of stratified random surveys so that survey results are more closely associated with particular habitats. The result is improved knowledge of the relationship between fish assemblages and habitat features. In addition, these surveys use alternative methodologies to extend survey coverage into all relevant habitats.
Life History		
0	None	No life history data.
1	Size	The size composition of harvested fish provides a simple index of a stock's potential and vulnerability to overharvesting.
2	Basic demographic parameters	Basic demographic parameters such as age, growth, and maturity rates provide information on productivity and natural mortality.
3	Seasonal or spatial information (mixing, migration)	Seasonal and spatial patterns of mixing, migration, and variability in life history characteristics, especially growth and maturity, provide improved understanding of how a population responds to its environment.
4	Food habits data	Food habits information defines predator-prey and competitive relationships within the fish community, thus providing a first step towards direct estimation of natural mortality rates and ecologically-based harvest recommendations.
Catch		
0	None	No catch data.
1	Landed catch	Landed catch provides a minimum estimate of fishery removals and is typically obtained from mandatory landing receipts. In some cases, particularly recreational fisheries, a statistical sampling program is used to expand estimates of sampled catch up to the total angling population.
2	Catch size composition	Catch size composition provides a measure of the sizes of fish being impacted by the fishery, and when tracked over time can provide an index of recruitment to the fishery and total mortality rates.
3	Spatial patterns (logbooks)	Spatial data on catch from logbooks can provide information on range extensions and contractions, and other changes in fleet or distribution.
4	Catch age composition	Catch age composition requires development of age determination techniques and an investment in the collection and processing of appropriate samples. The result is much greater stock assessment accuracy than can be obtained with size composition data alone.
5	Total catch by sector (observers)	Accurate and complete data on total removals (including landed catch, discards, bycatch in other fisheries, and cryptic mortality included by fishing gear contact) will contribute to accurate stock assessment results. An at-sea observer program can monitor total removals, cross-check logbook data, and collect site-specific biological samples. In many fisheries, the relative merits of observer programs for collecting data on total removals and/or age composition data may warrant consideration before or instead of investing in a fishery logbook program.
Anthropogenic Impacts other than Catch		
0	None	No information on human-caused impacts on survival or other demographic parameters.
1	Primary sources, with uncertainty or incompleteness	Primary sources of anthropogenic impacts have been identified, but the list is uncertain or incomplete and there is no quantitative information relating risk factors to demographic parameters.
2	Most primary sources identified, some quantified	Most primary sources of anthropogenic impacts have been identified and have been at least somewhat quantified based on literature reviews or data from other populations or species, or some sources may be accurately quantified but other potentially important sources of mortality remain unquantified.
3	All primary sources identified and somewhat quantified	All primary sources of anthropogenic impacts have been identified and have been at least somewhat quantified based on literature reviews or data from other populations or species, or some sources may be accurately quantified but other potentially important sources of mortality remain unquantified.
4	All primary sources identified and accurately quantified	All primary sources of anthropogenic mortality have been identified and accurately quantified.
Assessment/Model Quality		
0	None	Although some data may have been collected on this species, these data have not been examined beyond simple time series plots or tabulations of catch.
1	Index only (commercial or research CPUE)	Either: a) a time series of a (potentially-imprecise) abundance index calculated as raw or standardized CPUE in commercial, recreational, or survey vessel date, or b) a one-time estimation of absolute abundance made on the basis of tagging results, a depletion study, or some form of calibrated survey.
2	Simple life history equilibrium models	Simple equilibrium models applied to life history information. For example, yield per recruit or spawner per recruit functions based on mortality, growth, and maturity schedules; catch curve analysis; survival analysis; or length-based cohort analysis.
3	Aggregated population models	Equilibrium and non-equilibrium production models aggregated both spatially and over age and size; for example, the Schaefer model and the Pella-Tomlinson model.
4	Size/age/stage-structured models	Size, stage, or age-structured models such as cohort analysis and untuned and tuned VPA analyses, age-structured production models, CAGEAN, stock synthesis, size or age-structured Bayesian models, modified DeLury methods, and size or age-based mark-recapture models.
5	Add ecosystem (multispecies, environment), spatial, and seasonal analyses	Assessment models incorporating ecosystem considerations and spatial and seasonal analyses in addition to Levels 3 or 4. Ecosystem considerations include one or more of the following: a) one ore more time-varying parameters, either estimated as constrained series, or driven by environmental variables, b) multiple target species as state variables in the model, or c) living components of the ecosystem other than the target species included as state variables in the model.
Assessment Frequency		
0	No assessment conducted	Never: an assessment has never been conducted.
1	Most recent assessment is ≥10 years old	Infrequent: the most recent assessment was conducted more than three years ago.
2	Most recent assessment is 6-9 years old	Frequent or recent: the most recent assessment was conducted with in the last three years.
3	Most recent assessment is 2-5 years old	Annual or more: assessments are conducted at least annually.
4	Most recent assessment is ≤ 1 year old	

Table B-6. Factors used in evaluating ESA-listed sea turtle species assessments. Note that a species must be ranked 3 in all categories to be considered Tier 2 overall (adequate).

Categor	**Description**
Stock Identification	
0	No information (qualitative or otherwise) available
1	Structure inferred from analyses undertaken for other purposes (e.g., distribution, differences in trends, differences in life history)
2	Structure inferred from an analysis specifically aimed at investigating population differentiation (e.g., pollutants, stable isotopes, genetics, tagging)
3	Structure inferred from an integrative analysis of at least two lines of evidence of the type listed under Level 2
4	Estimates of dispersal rate that include estimates of uncertainty
Abundance: Nesting	
0	No information (qualitative or otherwise) available
1	Minimum count, abundance estimate, or index count
2	Unbiased estimate of abundance (CV≥30%)
3	Unbiased estimate of abundance (CV<30%) with seasonally OR geographically-explicit
4	Seasonal and geographic-specific density estimates
Abundance: In-Water	
0	No information (qualitative or otherwise) available
1	Minimum count, abundance estimate, or index count
2	Unbiased estimate of abundance (CV≥30%)
3	Unbiased estimate of abundance (CV<30%) with seasonally OR geographically-explicit
4	Seasonal and geographic-specific density estimates
Life History	
0	No information
1	Basic life history understood
2	Some age/stage parameters available
3	Age/stage parameters fully specified with uncertainty estimates
4	Temporal and/or spatial information available
Anthropogenic Impacts	
0	No information (qualitative or otherwise) available
1	Qualitative evidence of anthropogenic impacts
2	Minimum estimate of anthropogenic impacts
3	Unbiased estimate of anthropogenic impacts (CV≥30%)
4	Precise estimate of anthropogenic impacts (CV<30%) OR no evidence of human-induced
Assessment Quality	
0	No assessments conducted
1	Assessment with minimum abundance or index only
2	Assessment using simple deterministic models with defaults or proxies
3	Assessment using more advanced deterministic models without defaults or proxies
4	Assessment using species-specific sophisticated models, such as stochastic models, depletion models, or projection models (e.g., population viability analysis, PVA)
Assessment Frequency	
0	No assessment conducted
1	Most recent assessment is ≥10 years old
2	Most recent assessment is 6-9 years old
3	Most recent assessment is 2-5 years old
4	Most recent is ≤ 1 year old

Table B-7. Factors used in evaluating ESA-listed invertebrate assessments. Note that 2 species of abalone must be ranked 3 in all categories to be considered Tier 2 overall (adequate), but coral need only be ranked 2 across all factors to achieve overall Tier 2 rank.

Categor	Short Description	Long Description ("metadata")
Stock Identification		
0	None	No information (qualitative or otherwise) available.
1	Inferred from distribution and abundance	Structure inferred from spatial and temporal distribution and abundance.
2	Inferred from phenotypic and life history differences	Structure inferred from geographic variability in phenotypic and life history characteristics (e.g., morphological traits, contaminant profiles, parasite levels, fatty acid composition, elemental stable isotope composition, and life history characteristics such as fecundity, growth rate, size- and age-at-maturity, etc.). Phenotypic traits may be subject to environmental as well as genetic influences.
3	Inferred from genetics or applied tagging	Structure inferred from an analysis of population differentiation using techniques that are independent of environmental influences (e.g., genetics, applied tagging) and that provide estimates of migration rate (as larvae, juveniles, or adults) together with estimates of uncertainty.
4	Inferred from 2 lines of evidence from Level 3	Structure inferred from an integrative analysis of at least 2 lines of congruent evidence of the type listed under Level 3.
Abundance		
0	No information (qualitative or otherwise) available	No abundance data are available.
1	Minimum count or abundance estimates and/or imprecise presence/absence survey, e.g., presence/absence surveys	Relative abundance or occurrence index from presence-absence surveys. At this low level of information, there will only be a limited ability to track changes in stock abundance.
2	Qualitative surveys	Qualitative surveys providing density estimates, e.g., the use of randomly selected transects and quadrants for sessile animals will provide more accurate tracking of changes in stock abundance and will enable better estimation of current status relative to historical abundance.
3	Precise, quantitative surveys with size, age, and sex composition	Quantitative research surveys, as per Level 2, with known or estimated statistical power able to detect an acceptable level of change in density. The collection of size, age, and sex data (for sexually dimorphic species) will provide a means to statistically measure changes in size and age distributions and sex composition, as well as recruitment strength.
4	Precise, quantitative surveys, and in Level 3, conducted seasonally and habitat-specific	Habitat-specific quantitative surveys, as per Level 3, which employ the concept of stratified random surveys so that results are closely associated with particular habitats. This type of survey will result in improved knowledge of the relationship between invertebrate assemblages and habitat features.
Life History		
0	None	No life history data are available.
1	Size composition data	Size composition data, if representative of population size structure, provide a general idea of population growth and mortality (through modal progression analysis) and can be indicative of strong year classes and pulses in recruitment.
2	Basic demographic characteristics	Information on basic demographic characteristics, such as age structure, growth, maturity, and fecundity, helps estimate productivity and natural mortality.
3	Seasonal and spatial information	Data on seasonal and spatial variability in life history characteristics provide improved understanding of how a population responds to its environment.
4	Food habits and trophic interactions	Information on food habits that structure trophic interactions within the community, such as predator-prey and competitive relationships, provides a step towards better understanding and more reliable estimation of natural mortality and helps develop ecosystem-based management recommendations.
Threats		
0	None	No information on threats to survival or other demographic parameters.
1	Primary sources, with uncertainty or incompleteness	Primary sources of threats have been identified, but the list is uncertain or incomplete and there is no quantitative information relating risk factors to demographic parameters.
2	Most primary sources identified, some quantified	Most primary sources of threats have been identified and have been at least somewhat quantified based on literature reviews or data from other populations or species, or some sources may be accurately quantified but other potentially important sources of mortality remain unquantified.
3	All primary sources identified and somewhat quantified	All primary sources of threats have been identified and have been at least somewhat quantified based on literature reviews or data from other populations or species, or some sources may be accurately quantified but other potentially important sources of mortality remain unquantified.
4	All primary sources identified and accurately quantified	All primary sources of threats have been identified and accurately quantified.
Assessment Type		
0	None	No assessment has been developed.
1	Abundance index only	A time series of abundance index has been calculated based on catch and effort data from commercial or recreational fisheries and/or research surveys.
2	Aggregated production models	Equilibrium and non-equilibrium production models aggregated both spatially and over age and size; for example, the Schaefer model and the Pella-Tomlinson, aggregated both spatially and over size and age, have been used.
3	Size/stage/age-structured models	Size, stage, or age-structured models have been developed.
4	Models with ecosystem and/or spatial and seasonal analyses	Assessment models incorporating ecosystem considerations and spatial and seasonal analyses in addition to Levels 2 or 3. Ecosystem considerations might include time-varying parameters driven by climate or environmental variables, multiple target species, or other living components of the ecosystem included as state variables in the model.
Assessment Frequency		
0	No assessment conducted	Never: no assessment conducted.
1	Most recent assessment is ≥10 years old	Most recent assessment is ≥10 years old.
2	Most recent assessment is 6-9 years old	Most recent assessment is 6-9 years old.
3	Most recent assessment is 2-5 years old	Most recent assessment is 2-5 years old.
4	Most recent is ≤ 1 year old	Assessment completed in past year.

Spreadsheet of Potential Authorities (e.g. Statutes, Executive Orders) to Address Ocean Noise Issues*

***Note: This spreadsheet is an initial survey of potential authorities, and the authorities may not be applicable to address all instances of ocean noise.**

Authority	Pertinent Language	Citation	Comments
Domestic Authority			
Marine Mammal Protection Act		16 U.S.C. § 1361 et seq.	
Incidental Take Authorizations	The Secretary of Commerce must allow, upon request, the incidental, but not intentional, taking of small numbers of marine mammals by U.S. citizens who engage in a specified activity (other than commercial fishing) within a specified geographical region if certain findings are made and regulations are issued or, if the taking is limited to harassment, a notice of a proposed authorization is provided to the public for review. (Military readiness activities are exempt from the “small numbers” and “specified geographical region” limitation.)	16 U.S.C. § 1371(a)(5)(A) & (D)	NOAA must conduct an analysis to ensure taking 1) will have “negligible impact” on relevant species or stock and 2) will not have an “unmitigable adverse impact” on the availability of those species or stocks for subsistence uses; NOAA authorizations must prescribe "the means of effecting the least practicable adverse impact on such species or stock and its habitat, paying particular attention to rookeries, mating grounds, and areas of similar significance . . . ” (i.e., mitigation). Authorizations must include requirements for monitoring and reporting.
Permits for Incidental Taking or Importation of Marine Mammals in the Course of Commercial Fishing Operations	Permits for the incidental taking or importation of marine mammals in the course of commercial fishing operations shall specify "(D) any other terms or conditions which the Secretary deems appropriate."	16 U.S.C. § 1374(b)(2)(D)	The Secretary of Commerce can require mitigation of noise impacts during the course of commercial fishing operations as part of granting this permit.
General Rulemaking Authority	The Secretary of Commerce, in consultation with any other affected Federal agency, “shall prescribe such regulations as are necessary and appropriate to carry out the purposes of [Title I of the Act].”	16 U.S.C. § 1382(a)	Previously used as authority to issue the right whale ship-strike rule. This authority is also utilized by the NMFS Office of Sustainable Fisheries, Office of Protected Resources, and Office of Habitat Conservation.
Cooperation by Federal agencies	"Each Federal agency is authorized and directed to cooperate with the Secretary, in such manner as may be mutually agreeable, in carrying out the purposes of this subchapter."	16 U.S.C. § 1382(b)	
Cooperative Agreement	"The Secretary may enter into such contracts, leases, cooperative agreements, or other transactions as may be necessary to carry out the purposes of [title I] or title IV and on such terms as he deems appropriate with any Federal or State agency, public or private institution, or other person."	16 U.S.C. § 1382(c)	Establishing cooperative agreements with states, Alaska Natives, and other partners regarding marine mammal resources

Authority	Pertinent Language	Citation	Comments
Measures to Alleviate Impacts on Strategic Stocks	"If the Secretary determines, based on a stock assessment under section 117 or other significant new information obtained under this Act, that impacts on rookeries, mating grounds, or other areas of similar ecological significance to marine mammals may be causing the decline or impeding the recovery of a strategic stock, the Secretary may develop and implement conservation or management measures to alleviate those impacts. Such measures shall be developed and implemented after consultation with the Marine Mammal Commission and the appropriate Federal agencies and after notice and opportunity for public comment."	16 U.S.C. § 1382(e)	
Conservation Plans; Preparation and Implementation	"(2) Each [conservation] plan shall have the purpose of conserving and restoring the species or stock to its optimum sustainable population. The Secretary shall model such plans on recovery plans required under [section 4(f) of the Endangered Species Act of 1973 (16 U.S.C. 1533(f))]."	16 U.S.C. § 1383b(b)(2)	The ESA at 16 USC 1533(f)(1)(B)(i) says recovery plans shall incorporate "a description of such site-specific management actions as may be necessary to achieve the plan's goal for the conservation and survival of the species." MMPA conservation plans could have similar site-specific management actions to reduce ocean noise as a means to promote the conservation of the species or stock.
Stock Assessments	"Each draft stock assessment, based on the best scientific information available, shall—(3) estimate the annual human-caused mortality and serious injury of the stock by source and, for a strategic stock, other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey;"	16 U.S.C. § 1386(a)(3)	Can use stock assessments to identify sources of ocean noise that are having effects on marine mammal habitat or prey.
Regional Scientific Review Groups	"The regional scientific review groups shall advise the Secretary on--(B) uncertainties and research needed regarding stock separation, abundance, or trends, and factors affecting the distribution, size, or productivity of the stock . . . (D) research needed to identify modifications in fishing gear and practices likely to reduce the incidental mortality and serious injury of marine mammals in commercial fishing operations; (E) the actual, expected, or potential impacts of habitat destruction, including marine pollution and natural environmental change, on specific marine mammal species or stocks, and for strategic stocks, appropriate conservation or management measures to alleviate any such impacts; and (F) any other issue which the Secretary or the groups consider appropriate."	16 U.S.C. § 1386(d)(1)	Research ways ocean noise is affecting marine mammals and ways can modify those practices. This includes impacts on habitat, the marine environment, and specific marine mammal species or stocks.

Authority	Pertinent Language	Citation	Comments
Collecting Information on Marine Mammal Health and Stranding	"The Secretary shall, in consultation with the Secretary of the Interior, collect and update periodically, existing information on . . . (2) appropriate scientific literature on marine mammal health, disease, and rehabilitation; (3) strandings, which the Secretary shall compile and analyze, by region, to monitor species, numbers, conditions, and causes of illnesses and deaths of stranded marine mammals; and (4) other life history and reference level data, including marine mammal tissue analyses, that would allow comparison of the causes of illness and deaths in stranded marine mammals with physical, chemical, and biological environmental parameters."	16 U.S.C. §1421a(b)	Collect information on marine mammal health and strandings to determine if ocean noise is the cause of harm.
Stranding Response Agreements	"The Secretary may enter into an agreement under section 1382 (c) of this title with any person to take marine mammals under section 1379 (h)(1) of this title in response to a stranding."	16 U.S.C. § 1421b	Might have some responsibility to do noise assessment as part of entering into such an agreement.
Endangered Species Act		16 U.S.C. § 1531 et seq.	
Purposes and Policy	"(b) Purposes. The purposes of this chapter are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve the purposes of the treaties and conventions set forth in subsection (a) of this section. (c) Policy. (1) It is further declared to be the policy of Congress that all Federal departments and agencies shall seek to conserve endangered and threatened species and shall utilize their authorities in furtherance of the purposes of this Chapter."	16 U.S.C. § 1531(b)-(c)(1)	General statements of purpose and policy. Typically used as background or support in legal arguments.
Determination of Endangered and Threatened Species	"(1) The Secretary shall by regulation promulgated in accordance with subsection (b) determine whether any species is an endangered species or a threatened species because of any of the following factors: (A) the present or threatened destruction, modification, or curtailment of its habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; (E) other natural or manmade factors affecting its continued existence."	16 U.S.C. § 1533(a)(1)	(a)(1)(A) & (E) are particularly applicable to addressing ocean noise

Authority	Pertinent Language	Citation	Comments
What Qualifies as Critical Habitat	ESA requires the Federal government to the "maximum extent prudent and determinable" designate "critical habitat" for any species it lists under the ESA. Critical Habitat is defined as: (1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation."	16 U.S.C. § 1533(a)(3)	Note the exceptions specified in 16 U.S.C. § 1533(a)(3)(B) to what the Secretary shall designate as critical habitat. Also designations must be based on the best scientific data available but "after taking into consideration the economic impact, the impact on national security, and any other relevant impact, of specifying any particular area as critical habitat." 16 U.S.C. § 1533(b)(2). Once designated, Section 7 of the ESA says all Federal agencies must ensure that any actions they authorize, fund, or carry out are not likely to destroy or adversely modify critical habitat. Critical habitat requirements do not apply to citizens engaged in activities on private land that do not involve a Federal agency.
Review of Listed Species	"The Secretary shall— (A) conduct, at least once every five years, a review of all [listed] species . . . and (B) determine on the basis of such review whether any such species should "be removed from such list [or be changed in status from endangered to threatened or vice versa]."	16 U.S.C. § 1533(c)(2)	
Protective Regulations for Threatened Species	"Whenever any species is listed as a threatened species . . . the Secretary shall issue such regulations as he deems necessary and advisable to provide for the conservation of such species. The Secretary may by regulation prohibit with respect to any threatened species any act prohibited under section 9(a)(1), in the case of fish or wildlife, or section 9(a)(2), in the case of plants, with respect to endangered species; except that with respect to the taking of resident species of fish or wildlife, such regulations shall apply in any State which has entered into a cooperative agreement pursuant to section 6(c) of this Act only to the extent that such regulations have also been adopted by such State."	16 U.S.C. 1533(d)	

Authority	Pertinent Language	Citation	Comments
Recovery Plans	"The Secretary shall develop and implement plans (hereinafter in this subsection referred to as "recovery plans") for the conservation and survival of endangered species and threatened species listed pursuant to this section, unless he finds that such a plan will not promote the conservation of the species. The Secretary, in developing and implementing recovery plans, shall, to the maximum extent practicable— (A) give priority to those endangered species or threatened species, without regard to taxonomic classification, that are most likely to benefit from such plans, particularly those species that are, or may be, in conflict with construction or other development projects or other forms of economic activity; (B) incorporate in each plan— (i) a description of such site-specific management actions as may be necessary to achieve the plan's goal for the conservation and survival of the species; (ii) objective, measurable criteria which, when met, would result in a determination, in accordance with the provisions of this section, that the species be removed from the list; and (iii) estimates of the time required and the cost to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal."	16 U.S.C. § 1533(f)	"Site-specific management actions" can include actions to reduce ocean noise.
Monitoring Recovered Species	(1) The Secretary shall implement a system to monitor effectively for not less than five years the status of all species which have recovered (i.e., been removed from either the threatened or endangered lists) . . . . 2) "The Secretary shall make prompt use of the authority under Paragraph 7 of subsection (b) of this section to prevent a significant risk to the well being of any such recovered species."	16 U.S.C. § 1533(g)(1)-(2)	Paragraph 7 of subsection (b) refers to emergency regulations that take effect immediately upon the publication of the regulation in the Federal Register. These emergencies pose a significant risk to the well-being of any species of fish or wildlife or plants. If the monitoring of recovered species shows that ocean noise is posing a significant risk to the well being of recovered species, this section could be used to promulgate emergency regulations to address the ocean noise.
Management Agreements with States	"The Secretary may enter into agreements with any State for the administration and management of any area established for the conservation of endangered species or threatened species."	16 U.S.C. § 1535(b)	NOAA can provide support to states through cooperative agreements to conduct listed species research and conservation actions. Limited by available funding and priorities.
Cooperative Agreements with States	"[T]he Secretary is authorized to enter into a cooperative agreement in accordance with this section with any State which establishes and maintains an adequate and active program for the conservation of endangered species and threatened species."	16 U.S.C. § 1535(c)	Cooperative agreements between the federal government and any state could be signed that addressed ocean noise for the conservation of endangered species and threatened species.

Authority	Pertinent Language	Citation	Comments
Allocation of Funds to States	"The Secretary is authorized to provide financial assistance to any state . . . To assist in development of programs for the conservation of endangered and threatened species or to assist in monitoring the status of candidate species . . . and recovered species . . . ."	16 U.S.C. § 1535(d)	Several considerations listed in the Statute as the Secretary decides whether or not to provide financial assistance to a state that has a program addressing ocean noise.
Interagency Cooperation, Federal Agency Actions and Consultations	"The Secretary shall review other programs administered by him and utilize such programs in furtherance of the purposes of this [Act]. All other Federal agencies shall, in consultation with and with the assistance of the Secretary, utilize their authorities in furtherance of the purposes of this Act by carrying out programs for the conservation of endangered species and threatened species . . . ."	16 U.S.C. § 1536(a)(1)	Support for using programs and authorities to address ocean noise impacting endangered and threatened species.
Consultation with Federal Agencies	"Each Federal agency shall, in consultation with and with the assistance of the Secretary, insure that any action authorized, funded, or carried out by such agency … is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of [critical] habitat of such species . . . ."	16 U.S.C. § 1536(a)(2)	As discussed below, pursuant to 16 U.S.C. § 1536(b), if jeopardy or adverse modification is found, the Secretary must provide "reasonable and prudent alternatives"; if no jeopardy or adverse modification, the Secretary may include in the incidental take statement "reasonable and prudent measures" as necessary and appropriate, to minimize the impact of the take, and must specify the terms and conditions required to implement the measures.
Biological Opinion	Secretary shall provide a written statement "detailing how the agency action affects the species or its critical habitat." If jeopardy or adverse modification is found, the Secretary shall suggest "reasonable and prudent alternatives" that would not jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of critical habitat.	16 U.S.C. § 1536(b)(3)(A)	The biological opinion can be used to identify the impact of ocean noise and can lead to the identification of reasonable and prudent alternatives that minimize this impact.
Incidental Take Statement	If the Secretary determines the proposed action will result in the incidental taking of a listed species but will not cause jeopardy, it must include in its Biological Opinion an "incidental take statement" specifying, among other things, "the impact of such incidental taking on the species affected," "those reasonable and prudent measures that the Secretary considers necessary or appropriate to minimize such impact," and "the terms and conditions . . . that must be complied with by the Federal agency or applicant . . . to implement [the reasonable and prudent measures to minimize impact]."	16 U.S.C. § 1536(b)(4)	If the incidental taking of species is due to ocean noise, the Secretary can specify reasonable and prudent measures in the incidental take statement that the applicant must take to minimize that impact.

Authority	Pertinent Language	Citation	Comments
Financial Assistance to Worldwide Efforts	The President may use foreign currencies accruing to the United States government to provide to any foreign country "assistance in the development and management of programs in that country which the Secretary determines to be necessary or useful for the conservation of any endangered or threatened species . . . ."	16 U.S.C. § 1537(a)	Although the money source is limiting, the President can take unilateral action to provide assistance to conservation programs in other countries, which may include conservation programs addressing ocean noise.
Encouragement of Foreign Programs	"The Secretary, through the Secretary of State, shall encourage—(1) foreign countries to provide for the conservation of fish or wildlife and plants including endangered species and threatened species listed pursuant to section 1533 of this title; (2) the entering into of bilateral or multilateral agreements with foreign countries to provide for such conservation; and (3) foreign persons who directly or indirectly take fish or wildlife or plants in foreign countries or on the high seas for importation into the United States for commercial or other purposes to develop and carry out with such assistance as he may provide, conservation practices designed to enhance such fish or wildlife or plants and their habitat."	16 U.S.C. § 1537(b)	Subsection (b)(2) could be used to enter into a bilateral or multilateral agreement with foreign countries to provide for conservation by addressing ocean noise.
Incidental Take Permit	The Secretary may permit the taking of federally listed wildlife or fish if such taking is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity." The statute then requires the applicant to submit a Conservation Plan that includes steps the applicant will take to minimize and mitigate such impacts as well as what alternative actions the applicant has considered. Then, among other requirements, if the Secretary finds "the applicant will, to the maximum extent practicable, minimize and mitigate the impacts of such taking," the Secretary shall issue the permit.	16 U.S.C. § 1539(a)(1)(B)-(a)(2)(B)	The Conservation Plan submitted to obtain an incidental take permit can include ways to minimize and mitigate ocean noise.
Direct Take Permit	The Secretary may permit the taking of federally listed wildlife or fish if it is "for scientific purposes or to enhance the propagation or survival of the affected species . . . ." The statute has the same requirements in (a)(2) to obtain a direct take permit as it does to obtain an incidental take permit (see directly above).	16 U.S.C. § 1539(a)(1)(A) & (a)(2)(A)-(B)	
Regulations for Enforcement	The Secretary, Secretary of the Treasury, or the Secretary of the Department in which the Cost Guard is operating may issue “such regulations as may be appropriate to enforce this Act.”	16 U.S.C. § 1540(f)	Cited (along with 16 U.S.C. 1382(a) of the MMPA) as authority pursuant to which NOAA issued its final rulemaking regarding speed restrictions to reduce the threat of ship collisions with North Atlantic right whales.

Authority	Pertinent Language	Citation	Comments
National Marine Sanctuaries Act		16 U.S.C. § 1431 et seq.	
Consultation Requirement - Secretary's Recommended Alternatives and Failure to Follow the Alternatives	"If the Secretary finds that a Federal agency action is likely to destroy, cause the loss of, or injure a sanctuary resource, the Secretary shall . . . recommend reasonable and prudent alternatives . . . . If . . . a Federal agency takes an action other than an alternative recommended by the Secretary and such action results in the . . . loss of, or injury to a sanctuary resource, the . . . agency shall promptly prevent and mitigate further damage and restore or replace the sanctuary resource in the manner approved by the Secretary."	16 U.S.C. § 1434(d)(2) & (4)	Noise that is likely to harm any sanctuary resource is subject to the consultation requirement if it either results from a federal agency action or is authorized by a federal permit. The definition of "sanctuary resource" is broad and includes any living or non-living resource that contributes to the conservation, recreational, ecological, historical research, educational, or aesthetic value of a sanctuary.
Prohibited Activities	"It is unlawful for any person to- (1) destroy, cause the loss of, or injure any sanctuary resource managed under law or regulations for that sanctuary;"	16 U.S.C. § 1436(1)	
Regulations	"The Secretary may issue such regulations as may be necessary to carry out this chapter." (However, applicability of this provision would be limited to protection of Sanctuaries, which would vary by Sanctuary; each Sanctuary must specify in its "terms of designation" the types of activities that will be subject to regulation (see 15 C.F.R. Part 922))	16 U.S.C. § 1439	Office of National Marine Sanctuaries' regulations prohibit specific kinds of activities, describe and define the boundaries of the designated national marine sanctuaries, and set up a system of permits to allow the conduct of certain types of activities (that would otherwise not be allowed). While each Sanctuary has its own unique set of regulations, there are some regulatory prohibitions that are typical for many sanctuaries: (1) Discharging material or other matter into the sanctuary, (2) Disturbance of, construction on, or alteration of the seabed, (3) Disturbance of cultural resources, and (4) Exploring for, developing, or producing oil, gas, or minerals (with a grandfather clause for preexisting operations). In addition, some sanctuaries prohibit other activities, such as the disturbance of marine mammals, seabirds, and sea turtles, operation of aircraft in certain zones, use of personal watercraft, mineral mining and anchoring of vessels.
Damage Assessment	"The Secretary shall assess damages to sanctuary resources in accordance with section 1432(6) of this title."	16 U.S.C. § 1443(b)(2)	Section 312 of the NMSA is a natural resource damage provision of the statute and allows the Secretary to bring both in rem and actions for damages when there is an injury to sanctuary resources.

Authority	Pertinent Language	Citation	Comments
National Environmental Policy Act	"To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality."	42 U.S.C. § 4321 et seq.	
Declaration of National Environmental Policy	"(a) [I]t is the continuing policy of the Federal Government . . . to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to crate and maintain conditions under which man and nature can exist in harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans. (b) In order to carry out the policy set forth in this chapter, it is the continuing responsibility of the Federal Government to use all practicable means . . . to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may--1) fulfill the responsibilities of each generation as trustee of the environment for succeeding generations . . . 3) attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences; 4) preserve important historic, cultural, and natural aspects of our natural heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice. . . ."	42 U.S.C. § 4331(a)-(b)	This section of NEPA typically seen as language declaring the will of Congress at the time and not creating any affirmative duties that an agency can be sued under.

Authority	Pertinent Language	Citation	Comments
Responsibilities of Federal Agencies	Federal agencies shall "(A) utilize a systemic, interdisciplinary approach . . . in planning and in decision-making which may have an impact on man's environment; (B) identify and develop methods and procedures . . . [to] insure presently unqualified environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations; and (C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on--i) the environmental impact of the proposed action, ii) any adverse environmental effects which cannot be avoided should the proposal be implemented, iii) alternatives to the proposed action, iv) the relationship between local short-term uses of the man's environment and the maintenance and enhancement of long-term productivity, and v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."	42 U.S.C. § 4332(A)-(C)	Most important part of NEPA is 4332(C) since it requires an analysis of environmental impacts. While this requirement is procedural and agencies can still go forward with the action after complying with this procedural requirement, it still leads to the agency publicly identifying environmental impacts such as high levels of ocean noise. More info on what's required in this analysis can be found in the Council on Environmental Quality's regulations implementing NEPA. See 40 CFR Parts 1500-1508.
Magnuson-Stevens Fishery Management and Conservation Act		16 U.S.C. § 1801 et seq.	
Habitat Protection as a Goal	The MSA identifies the continuing loss of marine habitats as a long-term threat to fisheries and says "habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States," and states as a purpose "[promoting] the protection of essential fish habitat in the review of projects conducted under Federal permits, licenses, or other authorities that affect or have the potential to affect such habitat."	16 U.S.C. § 1801(a)(9) & (b)(7)	

Authority	Pertinent Language	Citation	Comments
Identification of Essential Fish Habitation and Preventing Harm to It	Fishery management plans (FMPs) must "describe and identify essential fish habitat for the fishery based on guidelines established by the Secretary . . ., minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat." Also, after it is identified, "Each Federal agency shall consult with the Secretary with respect to any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by such agency that may adversely affect any essential fish habitat identified under this Act."	16 U.S.C. § 1853(a)(7) & 16 U.S.C. 1855(b)(2)	"The term 'essential fish habitat' means those waters and substrate necessary to fish for spawning, breeding, or growth to maturity." 16 U.S.C. § 1802(10). Through consultations, NOAA recommends ways federal agencies can avoid or minimize the adverse effects of their actions on the habitat of federally managed commercial and recreational fisheries.
Other Necessary and Appropriate Measures to Conserve Fishery	FMPs may "prescribe such other measures, requirements, or conditions and restrictions as are determined to be necessary and appropriate for the conservation and management of the fishery."	16 U.S.C. § 1853(b)(14)	
Community-based Restoration Program	"(a) The Secretary of Commerce shall establish a community-based fishery and coastal habitat restoration program to implement and support the restoration of fishery and coastal habitats. (b) In carrying out the program, the Secretary may-- (7) promote stewardship of fishery and coastal habitats."	16 U.S.C. § 1891a(a) & (b)(7)	The NOAA Restoration Center (RC) implements and supports restoration of priority coastal, marine, and riverine habitats essential for the reproduction, growth, and sustainability of commercial and recreational fisheries. As part of its efforts, The RC provides a full range of restoration expertise and financial support for habitat restoration projects nationwide.
Coastal Zone Management Act		16 U.S.C. § 1451-1464 et seq.	
Consistency of Federal Activities with State Management Programs	"Each Federal agency activity within or outside the coastal zone that affects any land or water use or natural resource of the coastal zone shall be carried out in a manner which is consistent to the maximum extent practicable with the enforceable policies of approved State management programs. A Federal agency activity shall be subject to this paragraph unless" aforementioned paragraphs apply.	16 U.S.C. § 1456(c)(1)(A)	The federal consistency provision is a major incentive for states to join the national coastal management program and is a powerful tool that states use to manage coastal uses and resources and to facilitate cooperation and coordination with federal agencies. If a state management program addressed ocean noise, federal activities that this section applies to would have to be consistent with it to the maximum extent practicable. In addition, States may use federal consistency to "object" to or block issuance of federal permits for conduct of activities with acoustic effects on state coastal resources. The Secretary must then conduct an Appeal procedure which may result in the permit being enjoined.

Authority	Pertinent Language	Citation	Comments
Fish and Wildlife Coordination Act		16 U.S.C. § 661 et seq.	
Protection of Wildlife	"Secretary of the Interior is authorized (1) to provide assistance to, and cooperate with, Federal, State, and public or private agencies and organizations in the development, protection, rearing, and stocking of all species of wildlife, resources thereof, and their habitat, in controlling losses of the same from disease or other causes, in minimizing damages from overabundant species, in providing public shooting and fishing areas, including easements across public lands for access thereto, and in carrying out other measures necessary to effectuate the purposes of said sections."	16 U.S.C. § 661(1)	Provides the basic authority for the Fish and Wildlife Service's involvement in evaluating impacts to fish and wildlife from proposed water resource development projects.
Consultation with Federal Agencies for Water Resource Development Activities	"Whenever the waters of any stream or other body of water are proposed or authorized to be impounded, diverted, the channel deepened, or the stream or other body of water otherwise controlled or modified for any purpose whatever, including navigation and drainage, by any department or agency of the United States, or by any public or private agency under Federal permit or license, such department or agency first shall consult with the United States Fish and Wildlife Service, Department of the Interior, and with the head of the agency exercising administration over the wildlife resources of the particular State wherein the impoundment, diversion, or other control facility is to be constructed, with a view to the conservation of wildlife resources by preventing loss of and damage to such resources as well as providing for the development and improvement thereof in connection with such water-resource development."	16 U.S.C. § 662	The Fish and Wildlife Coordination Act requires that all federal agencies consult with NOAA Fisheries, U.S. Fish and Wildlife Service, and state wildlife agencies when proposed actions might result in modification of a natural stream or body of water. Federal agencies must consider effects that these projects would have on fish and wildlife development and provide for improvement of these resources.

Authority	Pertinent Language	Citation	Comments
Federal Power Act		16 U.S.C. § 791-828(c) (1920) as amended (*chapters not stated here*)	
Licensing Decisions	"In deciding whether to issue any license under this subchapter for any project, the Commission, in addition to the power and development purposes for which licenses are issued, shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality."	16 U.S.C. § 797 (e)	Directing the Commission to give equal consideration to both the impact on fish and wildlife (e.g., effects ocean noise from the project may have on fish and wildlife) and the additional power generation that would come from the project.
Conditions on Licenses for Water Power and Resources	"All licenses issued under this subchapter shall . . . as in the judgment of the Commission will be best adapted to a comprehensive plan for . . . the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat . . . ."	16 U.S.C. § 803(j)(1)	In FERC licensing process, NOAA Fisheries provides the perspective of migratory fish and their habitat, sometimes requiring alternative fish passage at dams to improve fish passage and recommending conditions to the license that will protect or improve habitat and fish populations.
Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act)	The RESTORE Act dedicates 80 percent of all Clean Water Act administrative and civil penalties related to the Deepwater Horizon spill to a Gulf Coast Restoration Trust Fund and outlines a structure by which the funds can be utilized to restore and protect the natural resources, ecosystems, fisheries, marine and wildlife habitats, beaches, coastal wetlands, and economy of the Gulf Coast region. Most of this money is distributed to 5 Gulf States (AL, FL, LA, MS, TX).	Public Law 112-141, Subtitle F- Gulf Coast Restoration; 126 Stat. 588 (July 2012)	The RESTORE Act established the Gulf Coast Ecosystem Restoration Council that developed a comprehensive plan to restore the ecosystem and the economy of the Gulf Coast region. Most money distributed under the RESTORE Act has to be for activities in this plan or activities consistent with the goals and objectives of the plan and must be approved by the Council.
The Mitchell Act		16 U.S.C. § 755-757	
Investigations, Surveys, and Experiments; Construction and Installation of Conservation Devices, Etc.	"The Secretary of Commerce is further authorized and directed (1) to conduct such investigations, and such engineering and biological surveys and experiments, as may be necessary to direct and facilitate conservation of the fishery resources of the Columbia River and its tributaries; (2) to construct and install devices in the Columbia River Basin for the improvement of feeding and spawning conditions for fish, for the protection of migratory fish from irrigation projects, and for facilitating free migration of fish over obstructions; and (3) to perform all other activities necessary for the conservation of fish in the Columbia River Basin in accordance with law."	16 U.S.C. § 756	Allows for investigations and experiments to determine if ocean noise is affecting the conservation of fishery resources of the Columbia River and its tributaries and also "all other activities necessary" for the conservation of these fish, which could include addressing ocean noise when the anadromous fish in the Columbia River are out at sea.

Authority	Pertinent Language	Citation	Comments
Anadromous Fish Conservation Act (AFCA)		16 U.S.C. § 757a-757g	
Development And Management with Regards to Anadromous and Great Lakes Fisheries	"The Secretary . . . is authorized . . . to conduct such studies and make such recommendations as the Secretary determines to be appropriate regarding the development and management of any stream or other body of water for the conservation and enhancement of anadromous fishery resources and the fish in the Great Lakes and Lake Champlain that ascend streams to spawn."	16 U.S.C. § 757b(5)	Mainly useful for conducting studies and information gathering
Park System Resource Protection Act		54 U.S.C. § 100721-100725	Act specifically allows the Secretary of the Interior to recover response costs and damages from the responsible party causing the destruction, loss of or injury to park system resources. National Park Service is entrusted with managing 11,000 miles of coast and 2.5 million acres of ocean and Great Lakes waters. http://www.nature.nps.gov/water/oceancoastal/.
Liability In Rem	"Any instrumentality, including a vessel, vehicle, aircraft, or other equipment that destroys, causes the loss of, or injures any System unit resource shall be liable in rem to the United States for response costs and damages resulting from the destruction, loss, or injury to the same extent as a person is liable under subsection (a)."	54 U.S.C. § 100722(b)	This Act only applies to National Park Service units as "System unit resource" means "any living or non-living resource that is located within the boundaries of a System unit"; The term "system" includes "any area of land and water administered by the Secretary [of the Interior], acting through the Director, for park, monument, historic, parkway, recreational, or other purposes." 54 U.S.C. § 100501. This Act provides that any monies recovered by the NPS may be used to reimburse the costs of response and damage assessment and to restore, replace, or acquire the equivalent of the injured resources.
Oil Pollution Act of 1990		33 U.S.C. § 2701 et seq.	
Trustee Plans	Directing the trustees (be they federal, state, Indiana tribe, or foreign) to "develop and implement a plan for the restoration, rehabilitation, replacement, or acquisition of the equivalent, of the natural resources under their trusteeship."	33 U.S.C. § 2706(c)	It is possible for this plan to include provisions addressing ocean noise to promote the restoration or rehabilitation of the natural resources under their trusteeship.

Authority	Pertinent Language	Citation	Comments
International Organizations			
International Maritime Organization (IMO)	The IMO is the UN specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. It is the forum at which regulations and standards for the shipping industry are agreed, adopted, and implemented on an international basis.	www.imo.org	The Marine Environment Protection Committee (MEPC) in 2014 in its 66th Session approved guidelines for the reduction of underwater noise from commercial shipping. These non-mandatory guidelines developed by the Sub-Committee on Ship Design and Equipment in 2013 in its 57th Session, address adverse impacts on marine life, recognizing that underwater noise radiating from commercial ships may have both short- and long-term negative consequences on marine life. Also, the Boston Traffic Separation Scheme (TSS) was reconfigured to reduce overlap with large whales. This could be adapted to avoid habitats of other acoustically sensitive marine life.
International Whaling Commission (IWC)	The IWC is the global body charged with the conservation of whales and the management of whaling. The IWC cannot independently enforce its regulations or sanction member nations engaging in activities that undermine the Commission's goals. Also, a member nation in opposition to any amendment instituted by the IWC can file a timely objection and then be considered exempt from that regulation.	www.iwc.int/home	The IWC has been studying the effect of ocean noise on cetaceans and has been working with other international organizations, in particular the IMO, as the IMO works to develop ship quieting technology and reduce ocean noise. In 2004 a mini-symposium was held to consider the issue of anthropogenic noise and a 2006 meeting focused on potential impacts of seismic surveys to various whale populations. More recently, in 2014 the IWC, NOAA, and others co-sponsored a joint workshop entitled "Predicting Soundfields--Global Soundscape Modeling to Inform Management of Cetaceans and Anthropogenic Noise." In 2016 the Environmental Concerns Group of the IWC Scientific Committee will focus on examining concerns related to the "masking" effect of anthropogenic sound on cetaceans.

Authority	Pertinent Language	Citation	Comments
International Organization for Standardization (ISO)	ISO is an independent, non-governmental organization with a membership of 162 national standards bodies. The American National Standards Institute (ANSI) is the sole U.S. representative and dues-paying member of the ISO. Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based market relevant international standards that support innovation and provide solutions to global challenges. ISO has published more than 20,500 international standards and related documents covering a wide variety of industries. A panel of experts discusses and negotiates a draft standard. Once the draft standard is completed, ISO's members vote on it and if a consensus is reached, the draft becomes an ISO standard.	http://www.iso.org/iso/home.html	When the IMO's MEPC sought to identify an appropriate method for measuring underwater noise incidentally generated by ships, the ISO began the development of such a method with the objective of ensuring reproducible measurements for the collection of underwater sound generated by commercial ships. The result was ISO 16554.3 that is titled "Ships and marine technology -- Measurement and reporting of underwater sound radiated from merchant ships -- Survey measurement in deep-water" and was published on February 25, 2014.
Relevant Executive Orders (EOs)			
EO 13547: Stewardship of the Ocean, Our Coasts, the Great Lakes	"This order adopts the recommendations of the Interagency Ocean Policy Task Force, except where otherwise provided in this order, and directs executive agencies to implement those recommendations under the guidance of a National Ocean Council. Based on those recommendations, this order establishes a national policy to ensure the protection, maintenance, and restoration of the health of ocean, coastal, and Great Lakes ecosystems and resources, enhance the sustainability of ocean and coastal economies, preserve our maritime heritage, support sustainable uses and access, provide for adaptive management to enhance our understanding of and capacity to respond to climate change and ocean acidification, and coordinate with our national security and foreign policy interests."	75 Fed. Reg. 43023 (July 22, 2010)	Directs agencies to implement policies including to protect, maintain, and restore the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources; and to participate in the process for coastal and marine spatial planning and comply with the National Ocean Council's certified coastal and marine spatial plans. The National Ocean Policy and related EO directs agencies to work with states and tribes develop a comprehensive regional plans for all ocean uses throughout the US EEZ. Fundamental to this effort is an ecosystem-based approach that seeks to sustain ecosystem functions and services (presumably including those related to the acoustic environment), while facilitating multiple, compatible uses. There is much potential for progress on acoustic issues in the accelerating national initiative.
EO 13158: Marine Protected Areas	"Marine protected area" means any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." "Identification of emerging threats and user conflicts affecting MPAs and appropriate, practical, and equitable management solutions, including effective enforcement strategies, to eliminate or reduce such threats and conflicts;"	65 Fed. Reg. 34909 (May 31, 2000)	Directs agencies whose authorities provide for the establishment or management of Marine Protected Areas (MPAs) to take appropriate actions to enhance or expand protection of existing MPAs and establish or recommend, as appropriate, new MPAs. Directs all Federal agencies, to the maximum extent practicable, to avoid harm to the natural and cultural resources that are protected by an MPA.

Authority	Pertinent Language	Citation	Comments
Presidential Proclamation 8031: Establishment of the Northwestern Hawaiian Islands Marine National Monument	"Except as otherwise provided in this proclamation, the Secretaries shall prohibit any person from conducting or causing to be conducted within the monument the following activities: 1. Removing, moving, taking, harvesting, possessing, injuring, disturbing, or damaging; or attempting to remove, move, take, harvest, possess, injure, disturb, or damage any living or nonliving monument resource; 2. Drilling into, dredging, or otherwise altering the submerged lands other than by anchoring a vessel; or constructing, placing, or abandoning any structure, material, or other matter on the submerged lands;"	http://www.gpo.gov/fdsys/pkg/CFR-2007-title3-vol1/pdf/CFR-2007-title3-vol1-proc8031.pdf (June 15, 2016)	Creates the NWHI monument; requires federal protection and management responsibilities; prohibits entering without federal permission; prohibits various activities, including oil and gas exploration, development, and production; prohibits explosives, drilling, and dredging; requires military activities to be carried out in a manner that avoids to the extent practicable and consistent with operational requirements, adverse impacts on monument resources and qualities; in the event of destruction, loss, or injury, the responsible military component shall take appropriate action to respond to and mitigate the harm and, if possible, restore or replace the monument resource or quality.

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