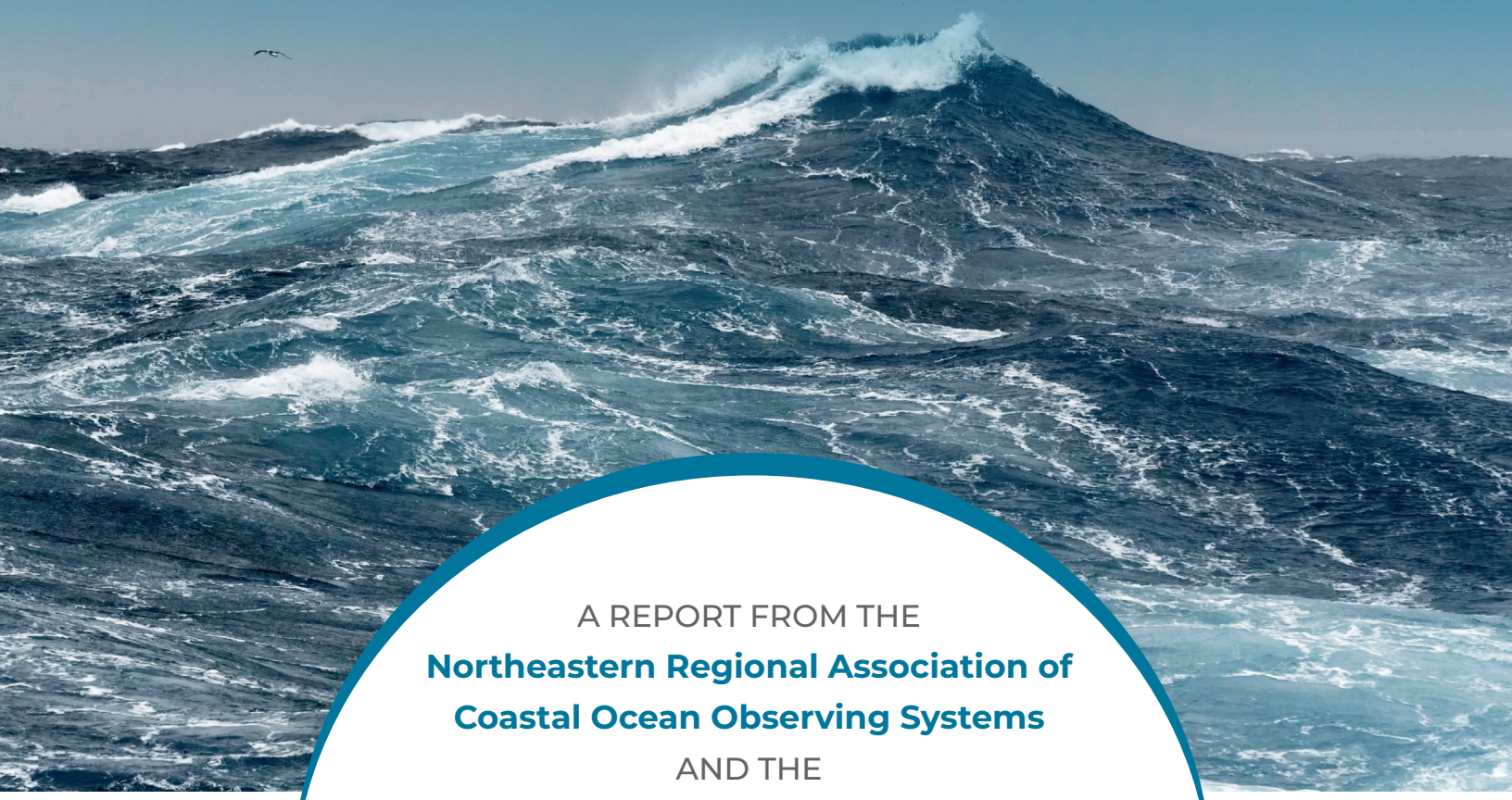
Science Implementation Plan

FOR THE **GULF OF MAINE REGIONAL ACOUSTIC NETWORK**



A REPORT FROM THE

Northeastern Regional Association of Coastal Ocean Observing Systems

AND THE

University of New Hampshire Center for Acoustics Research and Education

NERACOOS
NORTHEASTERN REGIONAL ASSOCIATION OF COASTAL OCEAN OBSERVING SYSTEMS

University of New Hampshire

ABOUT THIS PLAN

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY 4
2 INTRODUCTION & STRATEGIC CONTEXT 5
3 OVERVIEW OF THE GULF OF MAINE REGION 9
3.1 **Geography, Bathymetry, Oceanography** 9
3.1.1 The Northeast U.S. Continental Shelf Large Marine Ecosystem 9
3.1.2 North Atlantic Oceanography and Connection to the Gulf of Maine 10
3.2 **Long Term Acoustic Monitoring in the Gulf of Maine** 12
3.2.1 The Rapidly Changing Gulf of Maine 12
3.2.2 Ambient Acoustics in the Gulf of Maine 12
3.2.3 Biological Changes and their Impacts on the Soundscape 13
3.2.4 Observing Changes through Acoustic Backscatter 14
3.3 **Regional Coordination for Contextualizing Soundscapes and Acoustic Signals** 15
3.4 **An Infrastructure and Process for Acoustic Analysis** 17
4 SCIENTIFIC TOPIC AREAS TO ADVANCE ACOUSTIC SCIENCE IN THE GULF OF MAINE 19
4.1 **How do local and global environmental changes affect acoustic propagation and soundscapes?** 19
4.1.1 Local Environmental Changes and Their Impact on Acoustic 19
4.1.2 Regional / Global Environmental Changes and Their Impact on Acoustics 21
4.1.3 Temporal and Spatial Scale of Acoustic Observations 23
4.2 **How do acoustic measurements serve as an indicator of the benthic habitats and environmental processes?** 23
4.3 **How can hydrographic, biological, and acoustic models be integrated for future prediction?** 25
4.4 **What are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the GoM that we could utilize acoustics for?** 27
5 OVERVIEW OF ACOUSTIC RESEARCH AND MONITORING IN THE REGION 29
5.1 **Effort by Acoustic Methodology** 29
5.1.1 Active Acoustic Monitoring & Surveys 29
5.1.2 Passive Acoustic Monitoring 31
5.1.3 Acoustic Telemetry Stations 32
5.2 **Ongoing Federal Efforts** 33
5.2.1 NOAA Fisheries, Northeast Fisheries Science Center 34
5.2.2 NOAA Office of National Marine Sanctuaries.... 34
5.2.3 U.S. Geological Survey 34
5.2.4 Office of Naval Research 34
5.3 **Ongoing State Efforts** 35
5.3.1 Maine Department of Marine Resources 35
5.3.2 New Hampshire Fish and Game 35
5.3.3 Massachusetts Division of Marine Fisheries 35
5.4 **Ongoing Academic Efforts** 35
5.4.1 The Acoustic and Environmental Observation Network 36
5.4.2 Robots4Whales 36
5.4.3 Center for Coastal and Ocean Mapping Joint Hydrographic Center 37
6 OVERVIEW OF OCEAN OBSERVING IN THE REGION 38
6.1 **Federal Ocean Observing Programs** 38
6.1.1 Coastal Data Information Program (CDIP) 38
6.1.2 Physical Oceanography Real-Time System (PORTS) 38
6.1.3 National Data Buoy Center (NDBC) 39
6.1.4 Integrated Ocean Observing System (IOOS) 39
7 CONCLUSIONS AND SUMMARY 40
8 LITERATURE CITED 41
9 APPENDIX A: TOPIC AREA 4 EXPANDED 47
10 APPENDIX B: GOMRAN SIP WORKING GROUPS: 48
11 APPENDIX C: GOMRAN SIP WORKSHOP ATTENDEE ORGANIZATION: 49
12 APPENDIX D. ABBREVIATIONS AND ACRONYMS REFERENCE 51

1 EXECUTIVE SUMMARY

The Gulf of Maine is one of the most dynamic and rapidly changing marine environments on the planet. It supports extraordinary biological productivity and biodiversity while sustaining fisheries, shipping, energy development, and other uses of deep economic, cultural, and national security concern. Building scientific understanding that operates across the spatial and temporal scales at which the Gulf functions is essential to anticipating its future. Acoustic research and technology offer a path to meet that challenge.

Sound is the dominant carrier of information in the ocean, and acoustic methods provide a uniquely versatile toolkit, yielding insight into physical oceanography, seafloor structure, biological communities, and human activity alike. Over the past few decades, advances in instrumentation, data storage, and computation have dramatically expanded the scale and duration of acoustic observations. Federal agencies, state programs, academic institutions, and private organizations have each deployed an array of active acoustic, passive acoustic, and acoustic telemetry assets. These assets, however, have not fully coalesced into a single plan or program, nor been substantially integrated with other ocean observing systems. Increasing coordination among implementation partners on research and applications has the potential to reveal patterns and new knowledge that no single program could detect alone, and this is the goal of the Gulf of Maine Regional Acoustic Network (GOMRAN).

This Science Implementation Plan provides a framework for potential collaboration of these disparate data sets to coalesce and inform transformative acoustic-based science across the region.

These categories for future research include the following questions:

How do local and global environmental changes affect acoustic propagation and soundscapes?

How do acoustic measurements serve as an indicator of the benthic habitats and environmental processes?

How can hydrographic, biological, and acoustic models be integrated for future prediction?

What are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the Gulf of Maine that we could utilize acoustics for?

GOMRAN brought together the Gulf of Maine research community to consider transformative science that could be achieved under this framework for scientific inquiry.

2 INTRODUCTION & STRATEGIC CONTEXT

Acoustics is the science of sound, encompassing its production, transmission, and reception (NASEM, 2025). In the ocean, where light attenuates rapidly, sound serves as the dominant carrier of information across distance and depth, with both animals and humans using sound to communicate and gather information about the conditions around them. Underwater sounds carry information about the state of the ocean, indicating characteristics of sound sources and the media sounds have interacted with. Sound can also be used to measure physical properties of the water (e.g., temperature, salinity), objects within the water column (e.g., fish aggregations, turbulent microstructure), and characteristics of the seafloor (e.g., habitat type). Ocean acoustics is therefore a broad and diverse field that spans the fundamental study of sound, the engineering of systems to detect and interpret it, and the application of acoustic methods to observe and understand the marine environment. The fields of study that acoustic methods serve are far-reaching and interdisciplinary, spanning ecology, physical oceanography, geophysics, fisheries, and beyond. That acoustics touches so many disciplines reflects the utility and untapped potential of sound in the marine environment, generated by physical, biological, and anthropogenic processes alike, and shaped by the very oceanographic conditions that it can in turn be used to measure.

Since the propagation, production, scattering, and reflection of sound in the ocean are tightly linked to physical oceanographic processes, biological activity, and hydrographic conditions, acoustic methods serve as a versatile approach for understanding marine systems. Ocean sound was recently added to the list of essential ocean variables (EOVS) for the Global Ocean Observing System (GOOS, Tyack et al. 2023), and ocean acoustics is the basis for technologies critical to the blue economy, from fisheries to energy development. In 1998, the U.S. Navy acknowledged the importance of ocean acoustics by establishing it as the first of five National Naval Responsibilities, a designation for long-term technical and operational focus areas essential to maintaining naval superiority (ONR, 2000).

The study of sound and the practical application of acoustic methods is growing in prevalence, especially within the Gulf of Maine (GoM) where there is a long history of ocean observation.

Over the last several decades, acoustic methods have become an increasingly important and widespread component of these efforts. This growing prevalence is due in part to advances in technology supporting acoustic observations, developments in computational capacity to process the resulting data, and expanding interest in the detection of soniferous species, mapping of the seafloor and characterization of the marine soundscape. Data acquisition in ocean acoustics research is often broadly categorized by approach, including acoustic telemetry, active acoustics, and passive acoustics (Fig. 1). Acoustic telemetry is a method of tracking the movements and behavior of marine animals by attaching small transmitters (tags) to them that emit unique high-frequency sounds (pings), which are then detected by underwater receivers. Active acoustics, or sonar, involves the transmission of sounds that interact with the environment and return as echoes (or backscatter), the properties of which can be used to measure a number of marine variables in the water column and on the seafloor. Passive acoustic monitoring (PAM) is the listening for and detection of sounds in the environment produced from a wide variety of sources. Based on unique acoustic metrics of the received sound, PAM recordings can provide information on abiotic parameters such as anthropogenic disturbances, precipitation, wind, and waves, as well as biotic parameters such as species identification through vocalization.

FIGURE 1

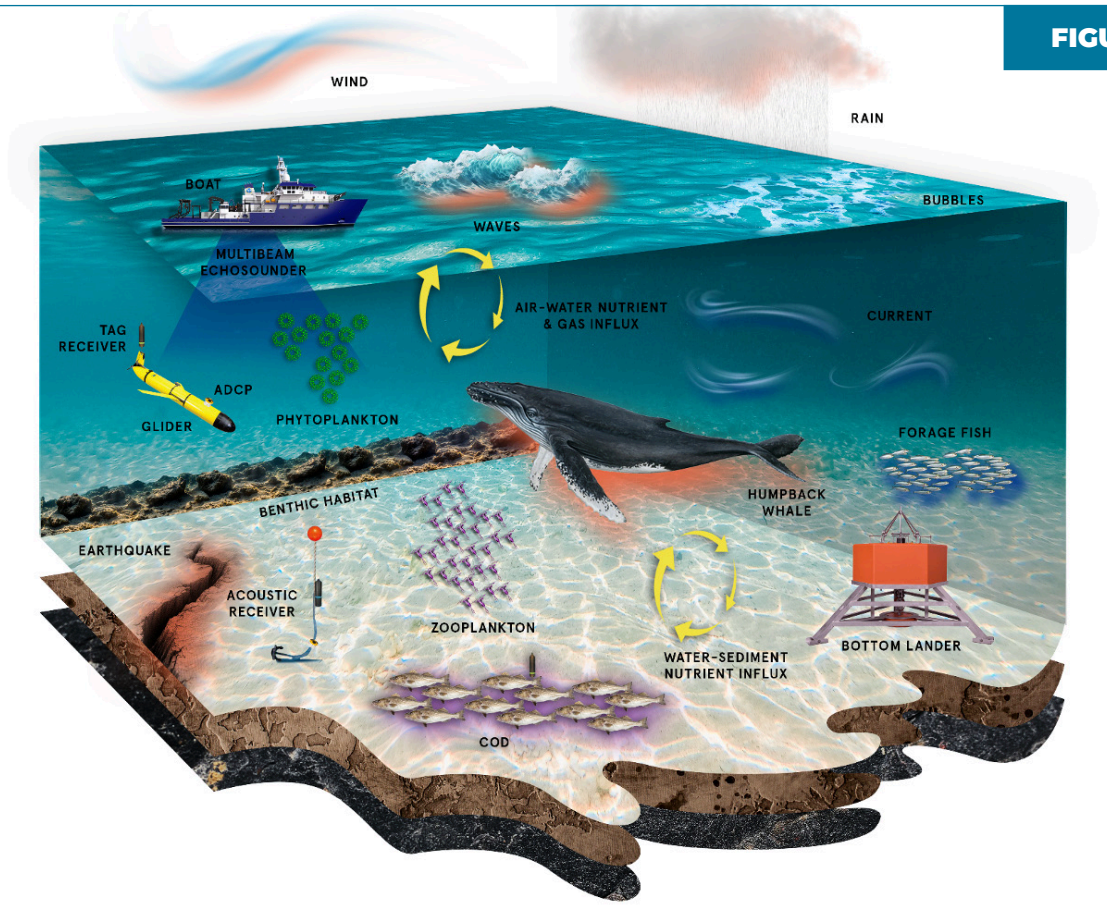


Figure 1. Conceptual overview of the application of acoustic methods for observing the marine environment. Depicted are common acoustic platforms and instruments (e.g. gliders, acoustic tag receivers) as well as phenomena and features that can be observed acoustically (e.g. benthic habitat, currents, bubbles). Red shading indicates sound sources primarily observed using passive acoustics, blue indicates active acoustic targets, and purple indicates those observable using both.

PAM is also the primary method used to characterize the marine soundscape. Soundscapes are formally defined by the ambient sound in terms of its spatial, temporal, and frequency attributes, and they include the collection of all sounds, both near and far, present at a given location (Tyack et al., 2023). The soundscape represents an interconnected landscape of sound sources that provide a comprehensive view of the acoustic information available to listeners (Barber et al., 2010). Since the Industrial Revolution, human activity has profoundly altered the ocean soundscape (Duarte et al., 2021). Shipping, resource exploration, and infrastructure development have increased anthropogenic sound generation across a broad range of frequencies, while biological sources of sound have been greatly altered by hunting, fishing, and habitat degradation. Meanwhile, soundscapes are being reshaped by ongoing physical changes in the ocean driven indirectly by human activity, including declining sea ice cover, increasing storm intensity, and shifts in water temperature and stratification that affect sound propagation (Duarte et al., 2021). Because biological, anthropogenic, and abiotic sounds can share similar acoustic properties, disentangling the occurrence and characteristics of all sounds present in a soundscape and understanding how they vary across space and time present significant analytical challenges that remain an active line of research (McKenna et al., 2021).

Typically, acoustic observations are enabled through five modes of deployment in either real-time or archival configurations: animal tags, mobile autonomous platforms, vessel-based surveys, fixed autonomous moorings or landers, and cabled observatories (Tyack et al., 2023). These data collection efforts range from short-term targeted research projects to long-term monitoring programs of considerable complexity. While each initiative may be designed differently to achieve a specific project goal, this mosaic of acoustic efforts, along with complementary non-acoustic ocean observing, has the potential to be collectively integrated across time and space to advance understanding of the abiotic and biotic aspects of the marine system.

In the GoM region, multiple institutions from academic, private and governmental sectors have greatly increased their deployment of active and especially passive acoustic monitoring arrays over the past decade (Howe et al., 2019). This increased observational effort presents an opportunity to expand our collective understanding of acoustic science and our knowledge of the GoM system generally. However, the diversity of efforts, combined with differing objectives and limited resources among participating institutions present significant coordination challenges. In recognition of this current landscape, the GoM Regional Acoustic Network Science Implementation Plans aims to elevate individually deployed assets and siloed efforts into an acoustic network that enables more powerful acoustic-based science and a comprehensive understanding of the GoM system. Davis and others (2017, 2020) demonstrated the value of regional coordination by pooling data from over 324 bottom-mounted recorders along the U.S. east coast from 2004 to 2014. This collaborative effort revealed that multiple large baleen whale species, including the endangered North Atlantic right whale (NARW), utilize the GoM year-round, that NARW acoustic presence in the region decreased after 2010, and that fin, blue, and sei whale detections increased over the same period. Collectively, these findings showed that baleen whale distributions shifted in alignment with climate and prey changes, with whales occupying new habitats in addition to previously known areas.



The work by Davis and others demonstrates the kind of transformative science that becomes possible when dispersed acoustic observations are connected and analyzed together. GOMRAN aspires to enable similar advances across the GoM by both linking disparate observational efforts and facilitating coordination among the institutions and researchers conducting them. This Science Implementation Plan serves as the roadmap to coordinate this regional science over the next five to ten years, with the goal of enabling transformative acoustic-based science in the GoM. The plan is the outcome of three workshops convened in 2025 and early 2026 that brought together acousticians, oceanographers, ecologists, and ocean observing practitioners from across the region to identify shared scientific priorities, existing capabilities, and gaps in the current observational landscape. The plan further identifies key scientific questions whose investigation, enabled by regional coordination, can advance understanding of the acoustic environment of the GoM and the environmental, ecological, and anthropogenic processes that shape and are shaped by it.

The science implementation plan is organized into the following major sections:

Overview of the Gulf of Maine Region: a summary of the geography, bathymetry and oceanography in the GoM, as well as the rapid and evolving changes observed in recent years.

Science Implementation Plan Topic Areas: four guiding scientific questions framing GOMRAN's research priorities, spanning environmental change and acoustic propagation, acoustic indicators of ecosystem processes, model integration, and emerging regional applications. These topic areas include:

- How do local and global environmental changes affect acoustic propagation and soundscapes?
- How do acoustic measurements serve as an indicator of the benthic habitats and environmental processes?
- How can hydrographic, biological, and acoustic models be integrated for future prediction?
- What are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the GoM that we could utilize acoustics for?

Overview of Acoustic Research and Monitoring in the Region: a synoptic survey of active acoustic, passive acoustic, and acoustic telemetry efforts across federal, state, and academic institutions.

Overview of Ocean Observing in the Region: a description of the major federal ocean observing programs operating in the GoM and the complementary regional and local assets that contextualize acoustic observations.

Conclusions & Summary: summarizes the needs to advance the science priorities identified in this plan and to sustain regional acoustic coordination over the coming decade.



3 OVERVIEW OF THE GULF OF MAINE REGION

3.1 Geography, Bathymetry, Oceanography

The Gulf of Maine (GoM) is a semi-enclosed basin on the continental shelf of the northwest Atlantic Ocean. As a geographic feature, it encompasses the northeastern extent of the United States territorial waters, bordered on the west by the New England states of Massachusetts, New Hampshire, and Maine, and further bordered by the Canadian provinces of New Brunswick and Nova Scotia to the north. The international boundary between the US and Canada, known as the Hague Line, passes through the eastern half of the GoM and extends to the southeast to the limit of the Exclusive Economic Zone. Thus, the GoM is not well defined by political boundaries, and instead the scope of the regional acoustic network is more meaningfully defined by the environmental and oceanographic context. One such effort to do so is the framework of Large Marine Ecosystems (LMEs) adopted by national and international management bodies, including NOAA's National Marine Fisheries Service (NMFS). Here, the LME framework is briefly reviewed, and its application to the GoM in order to identify the boundaries which will help inform the relevant scientific questions this network seeks to address by considering the scope of the region and the environmental context which shapes and intersects with the acoustics.

3.1.1 The Northeast U.S. Continental Shelf Large Marine Ecosystem

The GoM itself is not large enough to be considered a LME on its own but rather a region within the Northeast U.S. Continental Shelf LME. This LME can be divided into three ecological production units of more similar regions according to their bathymetry, hydrography, and primary productivity (Clark and Brown, 1977; Gamble et al. 2016, Fig. 2). The southernmost unit, the Mid-Atlantic Bight, stretches from Cape Hatteras to Cape Cod. The northeastern portion of the Mid-Atlantic Bight is also known as the Southern New England Shelf, and its boundary is marked by the Great South Channel, which connects the GoM to the wider Atlantic. On the east side of the Great South Channel is Georges Bank, a shallow plateau that marks the southern enclosure of the GoM. On the east end of Georges Bank is the Northeast Channel, the other passage between the GoM and the Atlantic. At deeper than 200 m, the Northeast Channel is much deeper than the Great South Channel's maximum 100 m depth and serves as the GoM's primary connection to the slope waters of the Atlantic. This deep channel connects directly to Georges Basin, one of the GoM's three deep basins, along with Wilkinson Basin in the west and Jordan Basin in the northeast. In the LME framework, the colloquial GoM is split into two units reflecting substantial oceanographic differences: the GoM itself in the west and the Scotian Shelf–Eastern GoM to the east. Generally, the eastern half of the GoM is colder and fresher than the west which reflects both the regional oceanography and the greater connection of the east to subarctic waters.



FIGURE 2

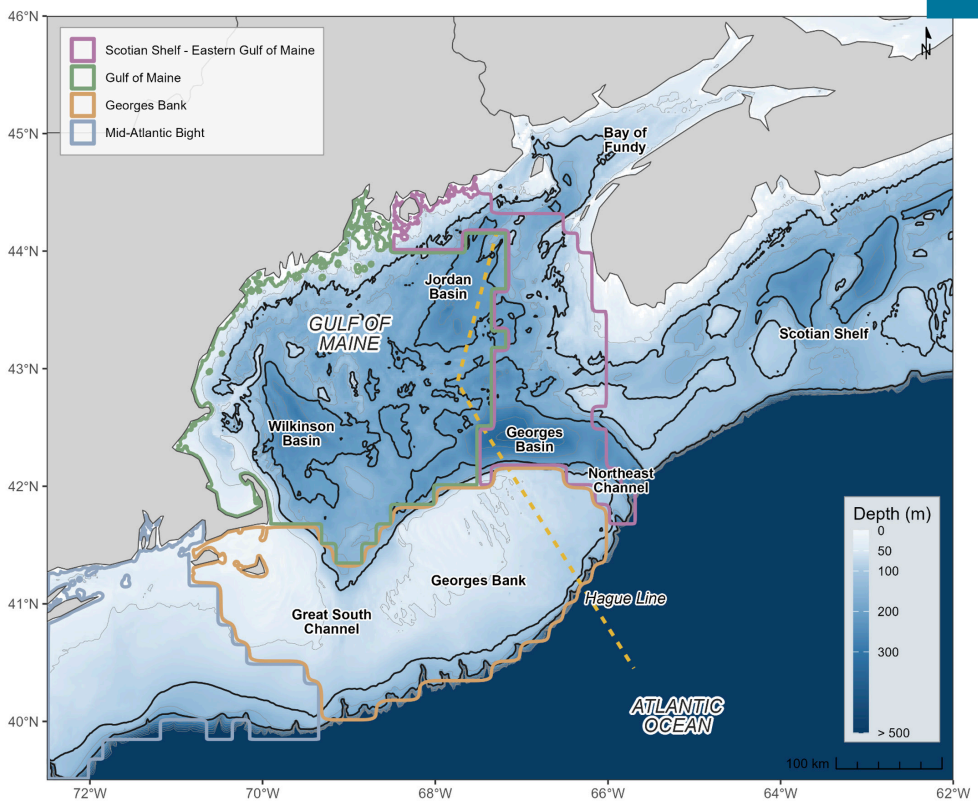


Figure 2. Gulf of Maine region bathymetry shown by color shading and contour lines, with bold isobaths at 100, 200, and 500 m; depths greater than 500 m are grouped into a single color class. Boundaries of four Ecological Production Units of the Northeast U.S. Continental Shelf Large Marine Ecosystem are indicated. The dashed gold line marks the maritime boundary between the United States and Canada within the Gulf of Maine, the "Hague Line" established in 1984; the seaward EEZ extension is not shown. Major features (e.g. basins, channels) are labeled.

3.1.2 North Atlantic Oceanography and Connection to the Gulf of Maine

Zooming out, the Northwest Atlantic is dominated by two prevailing currents within the larger subpolar Atlantic Meridional Overturning Circulation (AMOC): the Gulf Stream and Labrador Current (Fig. 3). The AMOC is the so-called conveyor belt of the Atlantic, responsible for regulating the climate through the bulk transport of warm, salty water from the tropics northward and the return of cool, relatively fresh water from the Arctic back southward. The primary artery of this northern movement of warm water is the Gulf Stream. Although this surface current lies far offshore of the continental break, it exerts a strong influence over the slope waters adjacent to the Northeast Shelf (NES) through mixing with smaller currents, including the eastward-flowing warm slope waters (New et al. 2021). Occasionally, eddies of the Gulf Stream will shear off from the general flow into warm-core rings, and those transported in a northerly direction may break on the continental shelf (Gangopadhyay et al. 2020). Warm-core rings have a profound impact on the physical, chemical, and biological oceanography of the slope sea that they pass through, as well as on the continental shelf, as evident by mid-water intrusions of higher-salinity water extending up to 100 km shoreward from the break (Gawarkiewicz et al. 2022).

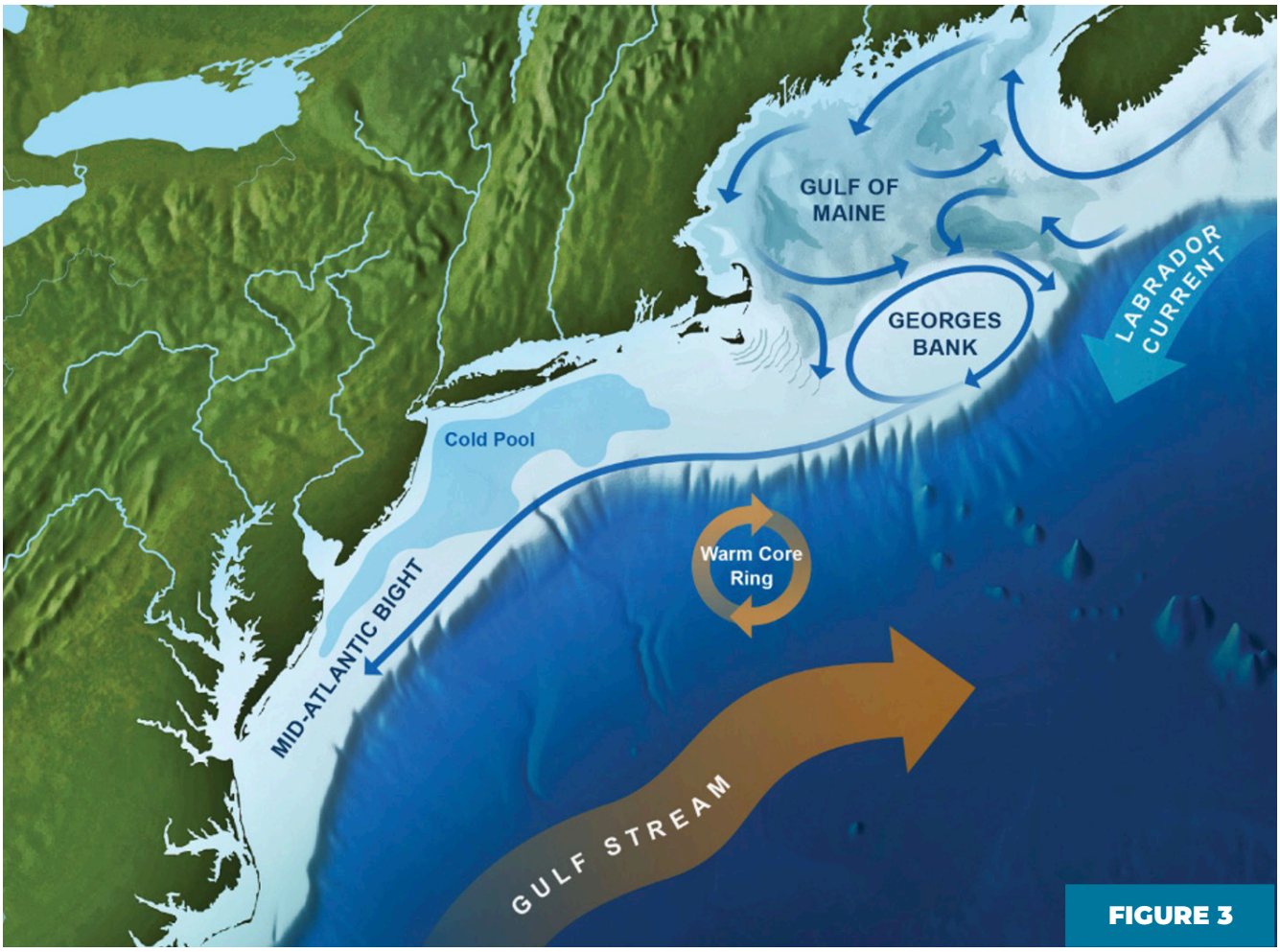


Figure 3. The U.S. northeast continental shelf (U.S. NES) marine ecosystem comprises the mid-Atlantic Bight, Georges Bank, and the Gulf of Maine. It is at the interface of two major currents: the warmer, saltier Gulf Stream deriving from the south, and the colder, fresher Labrador Current deriving from the north. These two currents form a recirculation gyre in the shelf slope and enter the U.S. NES via the northeast channel in the Gulf of Maine. Gulf Stream water can also enter the U.S. NES via anticyclonic warm core rings. The mid-Atlantic Bight cold pool is formed seasonally after each winter when wind forcing is reduced and the water column becomes stratified in the summer and early fall. The cold pool is critical habitat for many key commercial species such as yellowtail flounder and ocean quahog. Rivers and estuaries are also critical habitat for many diadromous species such as Atlantic salmon, river herring, and striped bass. (Base map file source https://www.shadedrelief.com/atlantic/. ;image and caption reprinted from Saba et al. 2023)

From the north, Labrador Slope Water connects the Arctic to the NES. After passing the Grand Banks, this branch of the AMOC transports cold, fresh water at depth westward along the continental break. At the Northeast Channel, this Labrador Slope Water, along with Warm Slope Water, has the opportunity to enter the GoM, bringing with it nutrients and a strong influence over the temperature and salinity regime of the Gulf (Townsend et al. 2023). These fluxes of deep water are evident in the basins of the Gulf by their water mass properties (temperature-salinity profiles and nutrient composition), where they can then mix with the overlying waters, especially in the winter months when thermal stratification breaks down and mixing is induced by storm events (Townsend et al. 2014).

In the surface waters, the GoM is also connected to the broader North Atlantic through the Nova Scotia Current, which originates in the Gulf of St. Lawrence and carries relatively cold, fresh water. The current enters the GoM from the western Scotian Shelf in Canadian waters, turns west, and then follows the coastline in a counterclockwise direction, transporting water centered on the 100 m isobath. Within the Gulf of Maine this current is the Maine Coastal Current (MCC), which eventually exits the GoM through the Great South Channel and the southern flank of Georges Bank (Fig. 3; Pettigrew et al., 2005). The MCC is influenced both by the upstream Nova Scotia Current and by the many inputs of riverine water. It is nutrient-rich, which, along with strong tidal mixing, helps sustain high primary productivity through the spring and summer months (Churchill et al., 2005). The MCC can be split into two distinct branches. Between its origin with the Nova Scotia Current and near Penobscot Bay is the Eastern MCC. West of Penobscot Bay is the Western MCC. The Eastern MCC is the stronger of the two. The weaker Western MCC is broader, more strongly influenced by river discharge, and thus more stratified and variable.

3.2 Long Term Acoustic Monitoring in the Gulf of Maine

3.2.1 The Rapidly Changing Gulf of Maine

The GoM is an environment experiencing rapid and unexpected changes. In an analysis of 30 years of sea surface temperature data, the GoM was found to be warming faster than 99% of the world's oceans (Pershing et al., 2015). This rapid warming of the GoM has been attributed to this influx of Warm Slope Water and changes in the AMOC, which has the potential to reverse course. Then in 2024, relatively cold water observations in the Jordan Basin and along the continental shelf break of Southern New England that departed from the recent warming trend were conjectured to be an early indicator of such a reversal (Townsend et al., 2023; Record et al. 2024; Gawarkiewicz 2026), but no trend has yet been identified.

3.2.2 Ambient Acoustics in the Gulf of Maine

Natural ambient sound is generated by processes including seismic activity, surface wave action, and precipitation. Recent observations from multiple NERACOOS buoys have documented changes in ocean currents and wind patterns in the GoM since 2001, with surface winds showing a strengthening of the southwesterly component (Burkholder et al., 2024). We can thus hypothesize that increased wind speeds have enhanced wave generation, which would contribute additional sound through wave breaking and bubble formation. Likewise, expected shifts in storm patterns, intensity, or precipitation amounts (Chisholm et al., 2021) could represent additional changes to ambient sound sources. Changes to precipitation patterns have already been documented in the state of Maine, with average annual precipitation increasing by approximately 15% since 1895 and more frequent heavy precipitation events observed since the late 1990s (Fernandez et al., 2020).

Furthermore, abiotic changes in the GoM influence sound propagation itself. The speed of sound in seawater is primarily determined by temperature, salinity, and pressure, with warmer and more saline water transmitting sound more rapidly. As the GoM continues to warm and water mass properties shift, sound propagation characteristics throughout the water column are also changing. The magnitude and spatial extent of these propagation changes, and their cumulative effects on the acoustic environment, remain areas of considerable uncertainty requiring continued monitoring and research.



3.2.3 Biological Changes and their Impacts on the Soundscape

While the GoM is a relatively small region, it is a highly varied and highly dynamic system as evident by the recent changes outlined above. The variety of habitats and species present, as well as their change over time (Runge et al., 2016), will necessarily alter the soundscape through the sounds they produce and the acoustic backscatter they generate in the water column and on the benthos. The GoM is also a highly studied system with a long history of human activity and resource exploitation that has shaped the ecosystem and its soundscape. Numerous species are commercially harvested from a variety of vessels using multiple types of fishing gear, from individual divers to purse seiners, and bottom trawlers whose impact on the bottom can be detected acoustically (Smith et al. 2007; Malik and Mayer 2007). These various stocks are likewise managed through many means, including catch limits, gear restrictions, and seasonal closures which determine the activity of the fishers and thus the sounds those activities produce. In 2024, the Georges Bank and GoM landings of managed stocks netted just over 180,000 metric tons, far below historical levels, and were valued at nearly $1.4 billion (NMFS Office of Science and Technology, 2026).

Atlantic cod form dense, site-faithful spawning aggregations during winter months, where males produce distinct low-frequency “grunts” during courtship to attract females and defend territory. A study by Caiger and others (2020) found that in Massachusetts Bay there was a general reduction in acoustic activity since 2009 that correlated significantly with the declining spawning stock biomass. The study demonstrates how passive acoustic monitoring can track population-level changes, though there is a lack of long-term recordings of the soundscape that would have allowed us to track the magnitude of change since the fisheries collapse in the 1990s. Despite the intensity of observations in the region, biological monitoring and management are particularly challenged in the GoM due to the system’s complexity, rate of change, and the high cost and limited scope of traditional methodologies such as trawl surveys and plankton net sampling. However, advances in acoustics over the last two decades have greatly increased the capacity for large-scale, long-term acoustic deployments (Wall et al., 2025), and these methods are well suited to address the observational challenges of the GoM.

3.2.4 Observing Changes through Acoustic Backscatter

Early echosounders were developed primarily for navigational purposes such as the detection of the seafloor, but during the Second World War, sonar systems detected a dynamic false bottom that was deeper during daytime and ascended at dusk. This phenomenon, later named the Deep Scattering Layer (DSL), was found to have a biological origin when depth-stratified net hauls revealed large concentrations of zooplankton, including copepods and euphausiids, at depths corresponding to the DSL (Colbo et al., 2014; Bandara et al. 2021). The DSL represented the location of diel vertically migrating zooplankton through the water column, and its discovery marked an early demonstration of acoustics as an ecological tool. Acoustic technology for characterization of particles and animals in the water column has advanced rapidly since then. Developments in broadband and multi-frequency echosounders have enabled the detection of different classes of objects in the water column by modulating the transmitted frequency, with higher frequencies resolving smaller targets such as zooplankton and lower frequencies better suited to detecting larger organisms such as fish. Certain taxonomic groups produce distinctive acoustic signatures due to their physical properties; for example, gas-bearing siphonophores are strong acoustic scatterers relative to their size. Concurrent advances in backscatter modelling techniques have improved the classification of detected targets based on their acoustic properties. The development of splitbeam transducers has further expanded observational capacity, enabling simultaneous monitoring of zooplankton prey and forage fish predators and revealing behavioral interactions such as predator-prey dynamics across depth and time (Skaret et al. 2020).

The acoustic environment can be altered by biological changes which in turn are linked to environmental drivers. Following the oceanographic shift of 2008, there was an observed change in plankton communities with a relative shift from larger to smaller zooplankton species and a particular decline in the abundance of the copepod Calanus finmarchicus (Dullaert et al. 2026, Pershing and Kemberling, 2024). In the North Atlantic, Calanus spp. dominate the mesozooplankton community in abundance and biomass and serve a critical ecological role in consuming primary productivity, storing that energy as lipids, and transferring the lipid energy throughout the food web (Melle et al. 2014). As a dominant mesozooplankton, *Calanus* copepods along with other zooplankton can alter the acoustic environment through their presence in the water column, as differences in size, composition, and density produce variations in acoustic backscatter as measured by echosounders.

In addition to their presence impacting the acoustic scatter, Calanus copepods are arguably the foundational species of the ecosystem, and their relative abundance is responsible for supporting lipid-dependent sub-arctic species like cod, herring, and many soniferous marine mammals, including the critically endangered North Atlantic right whale (NARW) (Record et al., 2019; Pershing and Stamieszkin, 2020). Interannual trends in the ecosystem further interact with species-specific phenologies and shifting seasonal patterns of habitat use. In Cape Cod Bay, Pendleton and others (2022) found that during this period of rapid warming, the date of peak habitat use shifted by +18.1 days for right whales and +19.1 days for humpback whales. For less mobile and adaptable species, these ecosystem-level changes can have population-level effects. For example, the recent decline in lobster recruitment has been attributed to a phenological mismatch with its larval prey, *Calanus finmarchicus* (Carloni et al., 2024). In the GoM region, oceanography drives ecosystem-level changes which have cascading effects on higher trophic level species, including those of cultural and commercial value. Acoustic approaches to scientific research can be utilized for better understanding these changes at multiple scales, but a key challenge to doing so is making the connections between dispersed efforts and siloed observations.



3.3 Regional Coordination for Contextualizing Soundscapes and Acoustic Signals

It is challenging to accurately interpret both passive and active acoustic signals without contextual information. Whether for seafloor mapping, passive acoustic monitoring, or fisheries and ecosystem surveys, a key obstacle in acoustics is the interpretation of sounds and backscatter signals. In some cases, particularly with vocalizations, a distinctive signal has a well-described pattern that can be reliably attributed to its source. Otherwise, gathering the best information requires ground-truthing the acoustic observations with visual surveys, sediment grabs, trawls, plankton net tows, or some other non-acoustic form of sampling. When it is not possible to ground-truth an observation, acousticians can gather insights into the likely source of the signal by leveraging the wealth of historical observational data and established ecological patterns already documented in the region. Owing to the long history of benthic, ecosystem, and fisheries data, it is often possible to make reasonably informed inferences about what animals would be in the water column or at the seafloor, and what substrate characteristics exist in a given area and time of year. Such interpretive work necessitates a network of interdisciplinary collaborators with access to datasets and the expertise to interpret them. Likewise, progress is being made in developing *in situ* sampling techniques such as automated imaging and eDNA identification (Yamahara et al., 2025), which have the potential to be powerful complementary methodologies to acoustics.

Here are opportunities to see the power of networks: 1) they connect researchers to the right information at the right time, 2) amplify individual efforts, and 3) enable rapid collective response. The rapid change occurring in the GoM has the potential to upend these information streams by disrupting the reliable phenological and distributional patterns that acousticians and other stakeholders have historically relied upon to interpret signals. A coordinated network of observations can be particularly useful in providing early indicators of such disruptions and extreme events, as was demonstrated during the 2023 *Tripos muelleri* bloom (Box A). This monospecific algal bloom was highly unusual in its duration, spatial extent, and intensity, dominating the western GoM from April through September of that year (Harvey et al., 2024). The bloom was initially detected piecemeal by individual researchers and stakeholders using various methods across different locations and times throughout the GoM. Only through network communication and coordination did the full picture emerge, revealing the bloom's identity, regional extent, and unprecedented nature.

The Highly Unusual Gulf of Maine Tripos Bloom

GoM seasonal phytoplankton blooms are typically dominated by diatoms that fuel a productive ecosystem comprising a variety of animal groups from benthic invertebrates to large whales (Bigelow, 1926, 1927). In 2023, an unusually dominant dinoflagellate *Tripos muelleri* bloom persisted in nearshore and offshore waters across the western GoM (Harvey et al., 2024). While Tripos muelleri naturally occurs in the region and had been commonly observed in prior years at concentrations ranging from 100 to 10,000 cells per liter, the 2023 bloom was unprecedented in its magnitude, duration, and spatial extent. Cell counts exceeded normal baselines by a factor of 10-50, with maximum concentrations surpassing 100,000 cells per liter (Harvey et al., 2024). The bloom extended vertically to depths of 30-40 m and was visible in satellite chlorophyll imagery, providing crucial spatial context for its regional distribution. Biogeochemically, the bloom resulted in the lowest surface water CO2 levels and highest pH levels observed in over 20 years, reflecting the massive carbon drawdown associated with this dinoflagellate's photosynthetic activity (Harvey et al., 2024). While *T. muelleri* does not produce harmful toxins, concerns arose about potential hypoxia development if the high biomass bloom sank to the seafloor where bacterial decomposition could deplete dissolved oxygen, potentially affecting fish, shellfish, lobster, and higher trophic level predators. Anecdotal reports from fishermen described "coffee-colored" or "dirty water," fishing gear covered in reddish-brown material, and notably fewer fish, birds, and whales in bloom-affected areas. However, by August the bloom had moved offshore in the western GoM and cell counts began declining. Although lower than usual dissolved oxygen levels were detected in Wilkinson Basin and Massachusetts Bay, no large hypoxic zone developed, possibly due to fall storm mixing and advection of dead Tripos away from the region (Harvey et al., 2024). The ultimate fate of the bloom remained undetermined, highlighting gaps in the monitoring network's ability to track the full lifecycle of such extreme events and their cascading ecosystem impacts.

In the aftermath of the bloom, researchers are actively investigating the extent of its impacts on the ecosystem, and acoustic observations collected by various institutions at multiple sites throughout the GoM have become a key component of that work. By combining passive acoustic monitoring with environmental observations across a wide spatial area over several years, researchers aim to detect the bloom's impact on the soundscape and identify acoustic indicators of such extreme events. The primary challenges in this analysis are the relatively short time series of passive acoustic monitoring data currently available in the region and the complexity of integrating diverse variables and expertise from multiple disciplines. Nevertheless, this ongoing investigation, born of GOMRAN collaborations exemplifies the benefits of such networks. The ability to synthesize acoustic data with coincident observations of temperature, salinity, dissolved oxygen, pH, and active acoustic backscatter from phytoplankton and zooplankton communities provides a more complete picture of how extreme bloom events cascade through the marine ecosystem and alter the underwater acoustic environment.

3.4 An Infrastructure and Process for Acoustic Analysis

Advancements in PAM technology over the last two decades have greatly enhanced the ability to characterize ocean soundscapes, detect soniferous species, and assess the impacts of anthropogenic sound. At the same time, cheaper and more accessible instrumentation, longer deployment periods, and growing interest from multiple sectors including state and federal agencies, offshore wind developers, and research institutions have led to an exponential growth in PAM data collection (Wall et al., 2021; Wall et al., 2025). The result is petabytes of data documenting ocean soundscapes across diverse environments, but this volume presents substantial challenges: the sheer size of the datasets, the heterogeneity of recording instruments and sampling regimens, and limited cyberinfrastructure capacity among many operators make coordination and comparison difficult. Furthermore, ensuring data quality through rigorous calibration and quality control is essential for producing accurate and comparable sound level measurements, yet practices can vary widely across projects. To realize the scientific potential of these observations, data must be managed according to FAIR principles (Findable, Accessible, Interoperable, Reusable), archived in publicly accessible repositories, and processed using standardized methods. This requirement would also extend to long term monitoring of the seafloor, which may include repeat multibeam backscatter mapping or data from bottom landers.



Scalable cloud infrastructure and community-supported best practices have the capacity to address many of these data management challenges. In keeping with the general cloud migration of federal agencies, the National Centers for Environmental Information (NCEI) has established a national archive for passive acoustic data that makes datasets available from deployments throughout U.S. waters (Wall et al., 2021). However, even with a centralized archive, the raw audio data remain too large for direct comparison or broad-scale analysis, and dimensional reduction through standardized acoustic metrics is therefore critical. The Sound Cooperative (SoundCoop) project, funded by NOAA, Bureau of Ocean Energy Management (BOEM), and the U.S. Navy, was created to address these challenges (Wall et al., 2025). Central to the effort is the creation of community-supported tools for proper metadata documentation, quality control, and processing of PAM data into hybrid millidecade (HMD) spectra, a standardized spectral summary that greatly reduces data volume while preserving essential acoustic information across frequency bands relevant to soundscape characterization (Martin et al., 2021; Wall et al., 2025).

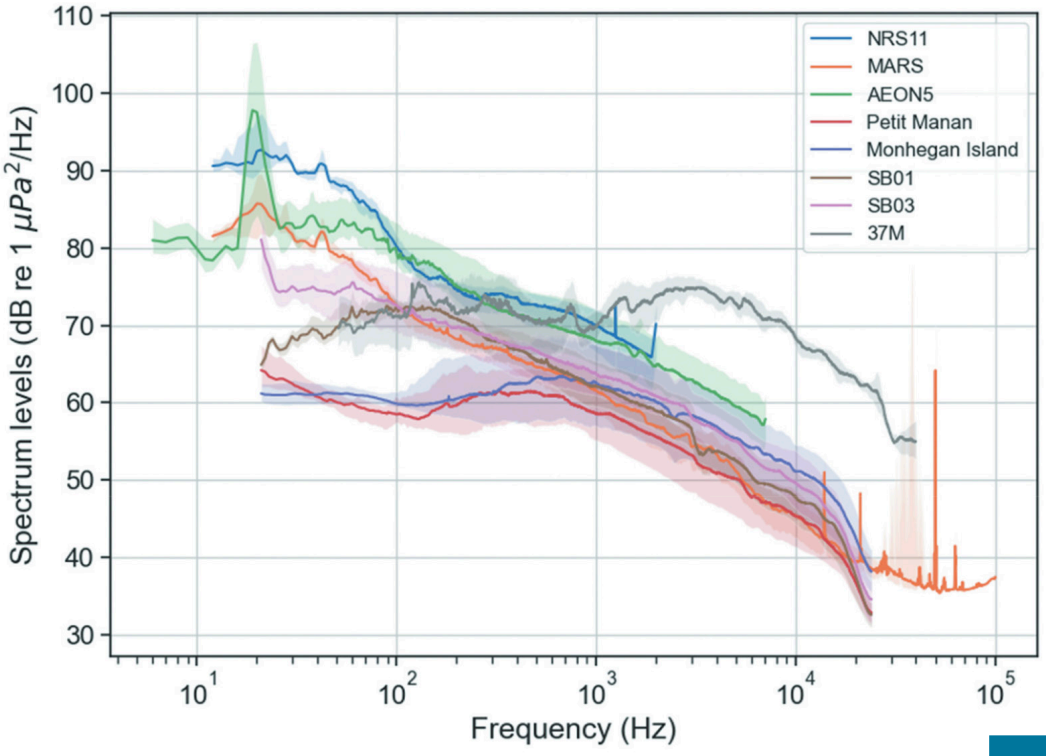


FIGURE 4

Figure 4. Example of passive acoustic datasets processed for hybrid millidecades to make regional comparisons. From Wall et al. 2025 "Figure 4. Large-scale comparisons of weekly-aggregated median power spectral density for eight sites recording throughout 2021. Sound levels are shown as the median (solid line) with 25th and 75th percentiles (shaded area)."

The potential of this framework is considerable. With standardized, interoperable sound level metrics, it becomes possible to examine large-scale spatial and temporal patterns in ocean soundscapes, compare conditions across monitoring programs, detect changes over time relative to reference periods, and integrate acoustic data with complementary environmental observations such as wind speed, wave height, and temperature (Fig. 4; Wall et al., 2021; Wall et al., 2025). These capabilities are essential for understanding how soundscapes are shaped by biological, physical, and anthropogenic drivers and how those relationships are changing. Although progress has been made to address these challenges, openly accessible cyberinfrastructure for processing, analyzing, and archiving PAM data is not yet widely available. Implementation of such infrastructure may be best achieved at a regional rather than national scale, since access to the infrastructure and the particular needs of data providers may require customized workflows. For example, in the GoM region, the primary motivation for the majority of PAM deployments is monitoring of the NARW, and any regional PAM processing framework should include detection and classification of their vocalizations as a core capability.

While the current focus of these data management and cyberinfrastructure efforts is on passive acoustic monitoring, an analogous challenge exists for active acoustic data, where similar issues of data volume, instrument diversity, and the need for standardized processing and archiving apply. The infrastructure and practices being developed for PAM provide a model that can be extended to support the broader integration of acoustic observations into ocean observing systems.

4 SCIENTIFIC TOPIC AREAS TO ADVANCE ACOUSTIC SCIENCE IN THE GULF OF MAINE

GOMRAN provides a framework to catalyze transformational acoustic science in the Gulf of Maine (GoM) through enhanced collaboration in the region. In pursuit of this vision GOMRAN brought together the acoustic and oceanographic community over a series of three workshops through an iterative and collaborative process to identify four topic areas for future acoustic research in the GoM. These topic areas include: *How do local and global environmental changes affect acoustic propagation and soundscapes? How do acoustic measurements serve as an indicator of the benthic habitats and environmental processes? How can hydrographic, biological, and acoustic models be integrated for future prediction? And what are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the GoM that we could utilize acoustics for?* Each Topic area is defined and explored further in the following sections.

4.1 How do local and global environmental changes affect acoustic propagation and soundscapes?

Environmental change in the GoM encompasses physical, chemical, and biological shifts that are driven by variability in climatic and anthropogenic activity and use patterns. The focus of this topic area is on how these environmental changes impact acoustics in the region, rather than delving into details of the specific types of changes. With this lens, impacts are grouped into two categories of origin: Local or Regional/Global. Local origin is meant to encompass environmental changes that are smaller scale (up to approximately 50 kilometers), driven by direct effects such as terrestrial runoff and ship traffic. These changes have impacts that are focused on one or more discrete locations within the GoM, not the entire region. Regional/Global origin are driven by larger scale processes (scales larger than approximately 50 kilometers) and dynamics, i.e. shifting weather patterns, major storm systems, and changes in global ocean circulation. The Regional/Global origin impacts on acoustics may still vary between specific locations within the GoM but are experienced across the entire region. While these two categories are not mutually exclusive, this grouping is used as a first order filter to organize the material presented in this section.

4.1.1 Local Environmental Changes and Their Impact on Acoustic

Environmental changes include both predicted and unanticipated environmental events such as harmful algal blooms, ship traffic, invasive marine species, marine mammal behavior, distribution and range of marine species, marine resource extraction, marine surveys, heat waves, and potential installation of offshore technologies. A comprehensive list of environmental changes that can impact acoustics with some examples of each impact are identified below.

These local changes (Table 1) impact acoustics by increasing sound levels and sources (i.e. ship traffic), changing geographical location or time patterns of sound sources (i.e. shifting species distributions and invasive species); and modifying the physical and chemical properties of seawater that affect the propagation of sound between source and receiver (i.e. heat waves). Many of these changes are already observed through robust observing systems in place in the GoM (see Sect. 8), however, there are some notable geographical gaps that are not well covered as can be seen in Section 7 “Overview of Acoustic Research and Monitoring in the Region”. These geographic gaps present opportunities to extrapolate between acoustic data points using physical and ecological models (see Topic Area 3, Sect 6.3), and as regions to target future measurements and studies (see Topic Area 4, Sect. 6.4).

4.1.2 Regional / Global Environmental Changes and Their Impact on Acoustics

Regional or global environmental changes (scales larger than approximately 50 kilometers) can impact the acoustics in a region just as those that occur on a more local regional scale. These changes may vary in intensity and / or rate, but are largely impacting a larger spatial scale. A comprehensive list of environmental changes with how each can connect to acoustics are identified below.

Table 1. Environmental changes relevant to ocean acoustics in the Gulf of Maine, grouped by spatial scale of change. Local-origin changes operate at smaller scales (up to approximately 50 km) and are driven by direct effects, while regional- and global-origin changes are driven by larger-scale processes and dynamics (scales greater than approximately 50 km). For each change, the table lists its origin, representative examples, and its connection to acoustics.

Origin	Environmental Change e.g.	Connection to Acoustics
Local	Substrate e.g. Mud, silts, sand, gravel, boulder, rock outcrop	Different substrates can impact how acoustics can travel through the water and penetrate the ocean floor
Local	Anthropogenic noise e.g. Vessels (commercial & recreational), construction, sonar, seismic	The addition of noise to the environment from human activity
Local	Structures e.g. Oil rigs, floating windmills, piers, jetties	Can impact marine sound propagation via reflection, scattering, or absorption of sound, as well as contribute to the soundscape
Local	Pollution e.g. Microplastics, ship discharge, hydrocarbon spills, ghost fishing gear, sewage outputs, chemical leaks	Can impact marine sound propagation via reflection, scattering, or absorption of sound, as well as contribute to the soundscape
Local	Marine Carbon Dioxide Removal (mCDR) e.g. Changes in chemical composition	Artificially enhancing the ocean as a carbon sink
Local	Resource Collection e.g. Fishing activity, energy collection	Addition of noise and impact of noise propagation through the marine environment
Local	Human Modification e.g. Energy infrastructure, research stations and gear, buoys	Input of structures into the marine environment can impact the propagation of marine sound
Local / Regional / Global	Stratification e.g. Scattering layers, surface mixed layer	Presence, absence, location and changes to stratification can impact marine acoustics

Local / Regional / Global	Coastal Resiliency e.g. Building sandbars, sensors deployments, wave attenuation, beach renourishment (particle contribution), dune restoration	Multifaceted efforts contributing to the adaption and recovering from coastal hazards, new or altered structures and substrate can impact sound propagation, human activities can contribute to the soundscape.
Local	River discharge e.g. Increases / decreases of fresh water input, level of sediment / pollutants in water input, exchange of marine life	Unknown inputs of fresh water (quantity, rate, contents, etc.) might impact how sound travels through the marine environment
Regional / Global	Glacial Melt	Unknown inputs of fresh water (quantity, rate, contents, etc.) might impact how sound travels through the marine environment
Regional / Global	Temperature	Varying temperature due to large ocean currents or regional temperature trends might cause changes to marine acoustic propagation
Regional / Global	Circulation	Variation in large ocean currents bring changes that can impact how sound propagates through the area
Regional / Global	Acidification	Changes in ocean pH can alter sound propagation, while the impacts on the ecosystem may alter the broader soundscape
Regional / Global	Sea Level Change	Changes (expansion and contractions) to the marine habitat may impact many acoustic variables through altered detection range, substrate characteristics, and presence of sound sources, etc.
Regional / Global	Interface Waves e.g. Variable air-sea turbulence can impact amount of air bubbles, nutrients, and attraction of marine life to the surface	Unpredictable or unknown variability in interface waves can change the composition of the marine environment
Regional / Global	Weather e.g. Storms, precipitation, input of nutrients	Variability in weather can change the environment of the marine habitat
Regional / Global	River discharge e.g. Increases / decreases of fresh water input, level of sediment / pollutants in water input, exchange of marine life	Unknown inputs of fresh water (quantity, rate, contents, etc.) might impact how sound travels through the marine environment

4.1.3 Temporal and Spatial Scale of Acoustic Observations

Current acoustic observations in the GoM provide context to the overall physical-biological environment, which is described in greater detail in Topic Area 2. In the cases of marine mammals, marine invertebrates, and fish, acoustic signals are contributing to the overall soundscape and ambient sound in different regions of the GoM. Study of individual bioacoustic signals offers insight into spatial and temporal distribution of different species within the GoM, and the arrival of new species that are introduced or experience a shift in their geographic ranges due to changing ocean conditions.

Certain source categories such as marine mammals have been studied for decades and are readily identified by both expert and relatively new users. Processing tools are also available to analyze for specific interpretive products to identify such things as marine mammals, water column backscatter, and benthic habitats. These analytical software packages include, but are not limited to Raven, Ishmael, Echoview and others. More recent work in bioacoustics has delved into identifying fish calls, fish species, and marine invertebrates from acoustic signatures (Mouy et al., 2023; Coquereau et al., 2016).

It is helpful to consider sound sources relative to their spatial extent and temporal duration, as is shown schematically in Figure 5 below.

FIGURE 5

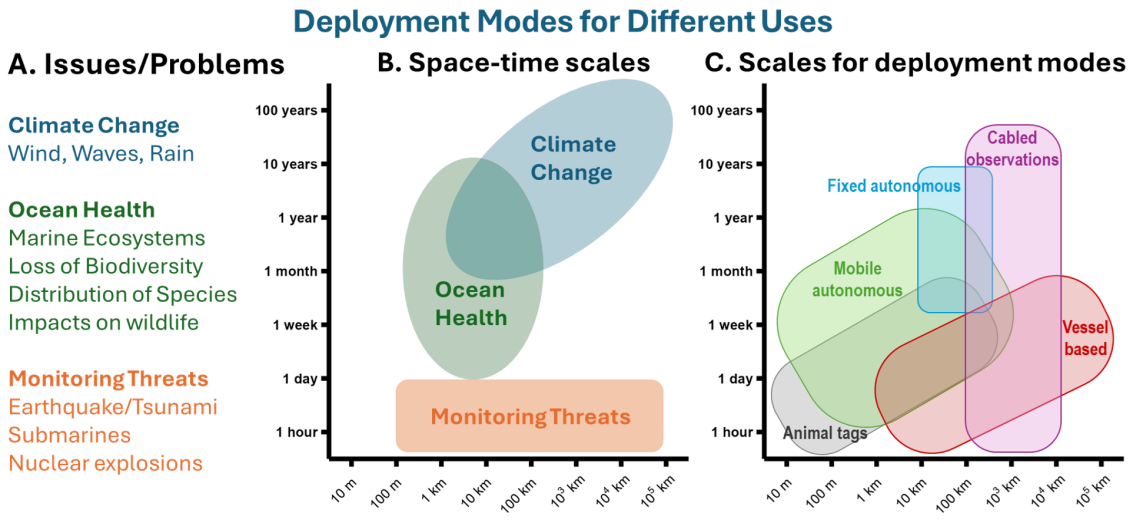


Figure 5. Overview of various modes of acoustic deployment and the types of research that can be addressed. A) color codes the main societal issues and problems for which the Ocean Sound EOV provides observations. B) uses the same color code to sketch the space-time scales required for observations relevant to each problem, and C) illustrates the space-time coverage that several modes of deployment of ocean acoustic sensors can provide. (adapted from Tyack et al. 2023 Fig. 4.1)

In addition to considering sound sources, there is also an effect on acoustic propagation as seawater properties shift due to various environmental changes. The most predominant is shifts in temperature, which can further lead to increased or decreased stratification. This affects how acoustic signals propagate, thus what sound sources can be perceived at any point within the GoM. Global and regional models suggest that the GoM will experience increased stratification in the near-term future, which may result in ducts and discrete sonic layers. Understanding the current and future propagation setting will be a key consideration for acoustic studies and applications including sensor placement and monitoring locations.

4.2 How do acoustic measurements serve as an indicator of the benthic habitats and environmental processes?

Changes in the acoustic environment are thought to serve as leading indicators, or sentinels, of large-scale changes in species population changes and migrations (Runge et al., 2016). The GOMRAN seeks to unify effort and advance science so that future large-scale changes can be predicted rather than studied in hindsight. The first step in such a plan is to determine how existing assets could be leveraged, while a longer-term view will inform what kinds of new measurements would be useful, and where they should occur.

Ongoing work using acoustic data to predict changes in environmental processes in the GoM is limited. However, in 2016 the Integrated Sentinel Monitoring Network Science and Implementation Plan (Runge et al., 2016) composed a series of sentinel questions and indicators. Of those questions and indicators, it is hypothesized that acoustics can be used to measure several. For example, high-frequency active acoustic systems can be used to estimate the abundance of key forage species such as euphausiids (Ressler et al. 2012), herring (NEFSC, 2025), and zooplankton (Greenlaw, 1979). Active acoustics can also be directed at the seabed itself with multibeam and sidescan backscatter yielding spatially continuous maps of the substrate and habitats that support various benthic communities (Brown et al. 2011; Misiuk and Brown, 2024). Because the benthic environment is inherently dynamic, repeat acoustic surveys offer a means to detect shifting habitat boundaries and substrate change over time, positioning seabed mapping as another sentinel of large-scale ecosystem change in the GoM. Meanwhile, passive acoustic monitoring (PAM) is routinely used to detect the presence and estimate the population densities of marine mammals; could changes in their distributions, movement patterns, or behaviors be leading indicators of underlying ecosystem change[1]? Furthermore, PAM is regularly used to study regional soundscapes and it's been postulated that changes in the Soundscape Code could be used as leading indicators of change (Milne, 2025). For example, changes in fish or marine mammal behavior is observable in soundscape data as are changes in anthropogenic activity which could predict stressors leading to widespread ecosystem impacts.

[1]Acoustic telemetry can provide more robust and persistent monitoring of species population dynamics, but has other practical limitations in some cases such as the ability to tag adequate numbers of species of interest.



In preparation for this science plan, leading experts identified acoustic measurements and information that could serve as sentinel indicators of the following processes and topics:

- Protected species
- Predator prey relationships
- Habitat change
- Primary production rates and composition
- Fishing pressure/resource harvesting
- Species composition
- Biodiversity
- Function Diversity
- Recruitment and settlement
- Fecundity
- Man made shifts
- Regime shifts
- Water column distribution of zooplankton

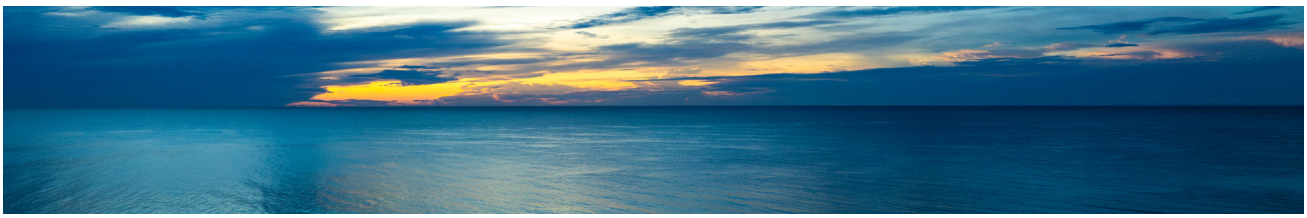
As presented in "Overview of Acoustic Research and Monitoring in the Region" (Sect. 7), there are a number of acoustic efforts within the GoM that collect passive and active acoustics, as well as acoustic telemetry detections. Active acoustics or sonar can be used to measure a number of marine variables in the water column and on the seafloor, including: seabed type and characteristics, species or trophic level identification and associated distribution and biomass. While sometimes measured at fixed stations (e.g. AEON, Sect. 7.4.1) these data are typically collected during deployments aboard moving platforms and are thus transitory in nature. Passive acoustic monitoring (PAM) is used to detect sound in the environment, and based on these unique sound characters it can provide information on abiotic parameters, such as anthropogenic disturbances, precipitation, wind and waves, as well as biotic parameters such as species identification through vocalization. Stationary archival PAM systems are in place throughout the GoM, allowing for persistent sources of information. Acoustic telemetry is used to track tagged individual movements, such as marine mammals and fish, over time. The reliability of acoustic telemetry data depends on the type of tag used, and varies from hours to months.

Rich datasets exist from which to investigate these research questions, and given the recent expansion of archival PAM throughout the GoM, many more data will be available in the future. If meaningful acoustic indicators of the ecosystem or environmental processes are identified and demonstrated to exist in current data, they could inform the planning of future monitoring networks to direct assets towards identified gaps.

4.3 How can hydrographic, biological, and acoustic models be integrated for future prediction?

Many tools currently exist for modeling hydrography, biology, and acoustics within the GoM. This topic asks the question of how these models can be used to advance the understanding of ocean acoustics and gain new insights, both individually and when these models are coupled together. Furthermore, this plan seeks to identify where gaps and bottlenecks exist for using models to address scientific questions.

Various hydrographic models have been applied to the GoM with the most prevalent being: the Finite-Volume Community Ocean Model (FVCOM)-based Northeast Coastal Ocean Forecast System (NECOFS, Beardsley and Chen 2014), Regional Ocean Modeling System (ROMS)-based GoM model (Lopez et al. 2020), various Hybrid Coordinate Ocean Model (HyCOM)-based models (Garraffo et al., 2020; Castillo-Trujillo et al., 2023), and the Advanced CIRCulation (ADCIRC) model (Xie et al., 2016). Several of these models, amongst others, have been coupled with biological models to produce ecosystem models of algal blooms (NCCOS, 2025), nitrogen cycling (Fennel et al., 2006), individual based models of prey (Thompson et al., 2025), and other applications. In addition to the hydrographic models, sound propagation models have been developed and utilized in the GoM. Parabolic Equation models (Ali and Lermusiaux, 2024) and normal-mode models (Kuperman and Roux, 2007) both predict low-frequency sound propagation. Parabolic equations predict over long distances, while normal-mode models are suited to shallow water. Additionally, ray-tracing models (Dushaw and Colosi, 1998) simulate sound propagation by representing the acoustic energy as discrete rays or beams. All three of these models are used routinely throughout the GoM and elsewhere.



The coupling of various models has the potential to answer many useful acoustic questions in the GoM. For example, could coupled hydrographic and species distribution models produce more accurate regional soundscape projections? Could marine mammal behavioral models combined with vessel movement models, such as those being produced by NOAA (Blondin et al., 2025) and MITRE, be used to reduce vessel collision risk in near real-time? Could ecological hotspot modeling be used for spatial gap identification? And could sound exposure modeling coupled with the modeling of additional anthropogenic or environmental stressors be used to perform risk assessments of cumulative impacts?

Focusing exclusively on acoustics, there are several areas in which models could be used in innovative ways to derive new insights and inform both science and policy. For example, how do economic impacts and variations affect acoustics within the GoM? How will environmentally-driven changes in sound propagation affect regulatory decision making? How does varying sea state impact relationships between vessel traffic, animal movement, and ambient noise? What will be the impacts of future storms and seasonal freshets on acoustic propagation? Answering the questions posed above will require addressing several gaps in existing models, which are summarized below (Table 2).

Table 2. Several gaps within various existing models have been identified that will be necessary to answer the questions posed in this Topic Area.

Current Gaps in Existing Models	Description of Gap
Sound and sea floor interactions	The variability of the seafloor and the difficulty of accurately mapping that variability impact the accuracy of the models
Small vessel traffic (non-AIS): Ship noise	Unpredictable noise input to the soundscape. Would allow for more accurate models accounting for sound propagation; including dissipation, interference
Small vessel traffic (non-AIS): Speed, depth, type	Unpredictable changes to the soundscape. By having more accurate knowledge of how non-AIS vessels move around in the GoM, it could allow for more accurate forecast and hindcast models.
Distribution of prey species	The knowledge or accurate prediction of prey species would greatly assist modeling of movements of species higher in trophic levels. For example: being able to know or predict the abundance and distribution of Calanus spp. would better allow a forecast model to tell us about the movements of the endangered North Atlantic Right Whale
Fisheries linked noise	Fishing activity is highly varied in terms of vessels and gear used, and fishing methods employed to target specific stocks. Each aspect adds noise to the soundscape. Accounting for these unique sound sources will improve soundscape analysis and may be used to improve models to predict species distribution, movements, and behavior.
Aquaculture linked noise	Aquaculture is rapidly growing in the GoM, the addition of gear, boat traffic, and anthropogenic presence surrounding a farm will have an impact on the local acoustics. The soundscape and nearby acoustic receivers might have interference due to unpredictable and difficult to account for noise input into the system. Depending on the aquaculture species, there may also be noise generated by the highly concentrated cultured animals.
Potential for hearing loss in animals	Many marine species rely on their hearing for communication, predator avoidance, and other biologically relevant sounds. There are anthropogenic sound inputs into the ocean without knowledge of how the ears of varying marine species are impacted
Relative contribution of anthropogenic, biological, geological sounds	Quantifying the contribution of sources of sound would allow more accurate local and regional models

4.4 What are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the GoM that we could utilize acoustics for?

Many areas of long-established research in acoustics, as well as emergent techniques and methods, have been described in Sections 5.2, and 6.1-6.3. This topic aims to highlight research areas in acoustics that are not yet established, per discussions amongst a panel of experts in Spring 2025 (Appendix B, Sect. 12). The topics highlighted were determined by the panel to be tractable by scientists today or within the next several years, with meaningful results emerging within the late 2020s and 2030s. Through this exercise, the workshop participants also came up with a list of research areas underway in acoustics. While some are mentioned in previous sections, a list of topics considered to fall in the category of "already being done" or beyond the scope of GOMRAN are included in Appendix A (Sect. 11).

The topics discussed in this section fall into two categories. The first, One Link Missing, covers areas that are within reach of current research but have not yet appeared in the scientific literature in combination with acoustics. Workshop participants also described this category as "short term" and "within reach" during brainstorming sessions (Table 3). The second category, Longer Term Focus Areas, covers topics that are further from current research known to the workshop participants but would be feasible on a multi-year to decade timescale. These areas would advance scientific knowledge and acoustic capabilities in the GoM, and more broadly in maritime and lacustrine settings (Table 4).

Table 3. One Link Missing: Areas of study identified during workshops that are within the scope of current research but have not yet been published in scientific literature incorporating acoustics. As each area of study is not yet published, assessment of current needs or status as defined in the working groups is included.

Area of Study	Assessment of Current Status/Needs
Marine debris detection	Acoustic detection of macro-plastics and ghost fishing gear are thought to be achievable in the near-future.
Diving sea bird measurements	Acoustic complements to other sensing and observational methods would be beneficial for the community.
Flux of gas exchange at air/sea interface related to bubbles	There is extensive work in underwater acoustics in bubble production and acoustics of bubbles, dating back to Minnaert in the 1920s. Relating acoustic-based bubble measurements to flux at the air-sea interface remains a gap.
Acoustically measuring bioturbation at seafloor	This is viable with instruments that are utilized today if oriented towards the seafloor, likely simultaneous with surveys of species presence responsible for bioturbation
Chemical changes in seawater	Chemical properties of seawater including salinity and pH affect the speed of sound, thus can theoretically be measured through long range acoustic propagation similar to temperature measurements through Acoustic Thermometry of the Ocean. Some work is being conducted in this area by David Barclay's group at Dalhousie University.

Table 4. Longer Term Focus Areas: Areas of study identified during workshops that are more distant to current research known to the workshop participants, but would be feasible on a multi-year to decade time scale. As each area of study is not yet feasible, hypothetical research avenues as defined in the working groups are included.

Area of Study	Assessment of Current Status/Needs
Measuring phytoplankton	Algal Bloom Detection, productivity and classification.
Measuring microbes	Acoustic detection of microbes (presentation or concentration); can this be an early indicator of ecosystem health?
Whale fall detection (hotspots of biological activity)	Does the whale fall affect the local soundscape? Assuming yes, due to increase in biological activity, could you use acoustics to detect whale falls?
Microplastics detection	Could acoustic trapping be viable in the ocean? Detection and imaging using high-frequency acoustics and multi-modal sensing, could be an opportunity to develop new sensors or technology. Tagging of microplastic debris to study transportation and accumulation, and infer mesoscale circulation in the GoM.
Earthquakes	Physical / Environmental observations associated with seismic activity, not necessarily early warning. It's unlikely that ocean acoustics would be more effective than existing seismic networks for earthquake monitoring and warnings.
Acoustic Telemetry Network	Usage of detection rates to infer weather and wind patterns over broad areas that may not be covered by NOAA buoys
Measuring/tracking biofouling and succession on recovered acoustic platforms	Leverage acoustic assets and collect scraped samples or photographs when instruments are recovered/exchanged to establish long-term timeline of biofouling and succession on different surfaces in the GoM.





5 OVERVIEW OF ACOUSTIC RESEARCH AND MONITORING IN THE REGION

Both active and passive methodologies help scientists better understand the Gulf of Maine system. The geographical boundaries, the primary oceanographic, and bathymetric features, and some of the ecological systems within the GoM can influence and be influenced by the acoustics that also exist in the system. Both passive and active acoustics efforts in the GoM range from short-term targeted research projects to highly complex long-term monitoring programs. An inventory of these data collection efforts in the GoM is provided in the subsequent section, which includes an overview of the methodology employed and the type of institution leading the observations.

5.1 Effort by Acoustic Methodology

5.1.1 Active Acoustic Monitoring & Surveys

Active acoustics or sonar can be used to measure a number of marine variables in the water column and on the seafloor, including: water velocities via Acoustic Doppler Current Profiler (ADCP), seabed type and characteristics via multi-beam echosounders and side-scan sonar, and species or trophic level identification of plankton and fish, as well as their associated distribution and biomass via echosounders. Tracking of these variables over time can lead to an increased understanding of changes in a system and identify unseen phenomena that may be occurring below the sea surface (Casalbore, 2024). As seen below (Fig 6) the coastal waters of the GoM have been densely monitored. Many of these historical data sets are archived at NCEI (Wall et al., 2016).

FIGURE 6

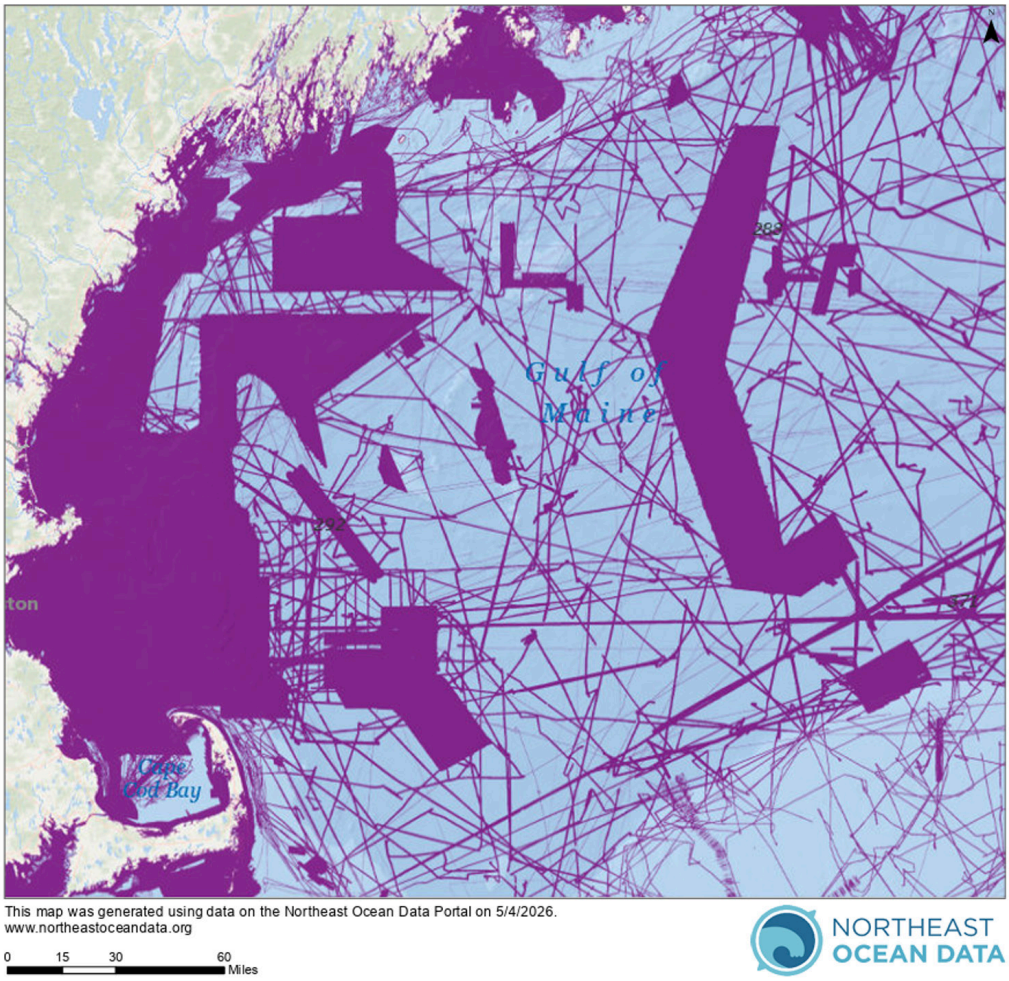


Figure 6. Cumulative bathymetry data in the Gulf of Maine since 1960. The dark purple indicates that the sounding data is of higher density (3 or more soundings per ~100m cell). Map figure downloaded from the Northeast Regional Ocean Council. Northeast Ocean Data Portal, www.northeastoceandata.org. Accessed: 05/04/2026



5.1.2 Passive Acoustic Monitoring

PAM is used to detect sound in the environment, and based on unique acoustic properties, it can provide information on abiotic parameters, such as anthropogenic disturbances, precipitation, wind and waves, as well as biotic parameters such as species identification through vocalization. Collection of passive acoustic data has drastically increased in recent years in the GoM (Figure 7). The Regional Wildlife Science Collaborative (RWSC) maintains an inventory of current deployments along the U.S. Atlantic coast, and as part of this effort meta-data is collected on each deployment. Metadata fields include, but are not limited to: project name, site name, latitude, longitude, instrument, status of co-deployment, deployment status, deployment start and anticipated end date, and a project web link to learn more.

FIGURE 7

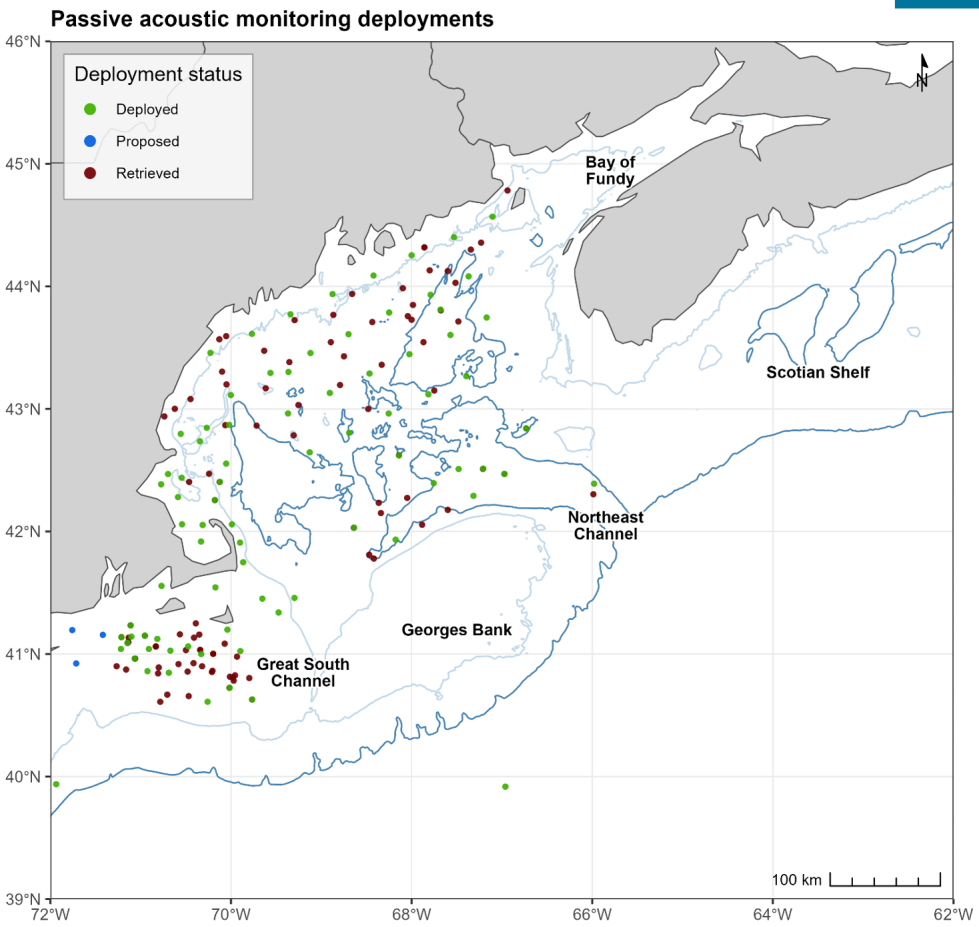


Figure 7. PAM deployments in the Gulf of Maine since 2014 (39–46°N, 72–62°W) with major features and the 75 m and 200 m isobaths depicted. Each point marks one station; color denotes project status at the time of data retrieval on 2026-06-25 from the Regional Wildlife Science Collaborative (RWSC, https://rwsc.env.duke.edu/arcgis/rest/services/Passive_Acoustic_Monitoring/MapServer/1)

5.1.3 Acoustic Telemetry Stations

Acoustic telemetry is being used to track the movements of individual animals as they traverse marine habitats. Electronic tags attached or inserted into animals communicate with listening devices ("receivers") placed throughout the GoM, providing individual-level information on animal presence. Across researchers and institutions, there are hundreds of locations listening for the "pings" of tags, allowing researchers to identify movements, habitat use, and large-scale migrations across a variety of species from crustaceans to sharks to fishes of commercial and recreational value. These data are invaluable in identifying key habitats, determining timing of key life stages such as migration and reproduction, and help to delineate boundaries for protected areas and fishing regulations (Crossin et al., 2017). Acoustic telemetry receivers in the GoM are often paired with other devices such as passive acoustic technology or water quality loggers, allowing researchers to identify environmental and biological conditions that may affect animal movements.

A global network of acoustic telemetry stations exists through the Ocean Tracking Network (OTN). Researchers that contribute to OTN are able to access species detection information of individuals that they tag. Eventually, these detections are then made accessible in OBIS, the Ocean Biodiversity Information System. Nationally and regionally, groups can work with telemetry nodes of the OTN to access and integrate telemetry detection information. Within the United States the Animal Tracking Network (ATN) coordinates a network of regional acoustic nodes. GoM researchers are already contributing tag detections to the OTN and the Atlantic Cooperative Telemetry (ACT) Network to make their acoustic telemetry information available. According to ACT there are currently 3,546 receiver stations and 87 gliders collecting information on tagged individuals in the Northwest Atlantic (Figure 8).

FIGURE 8

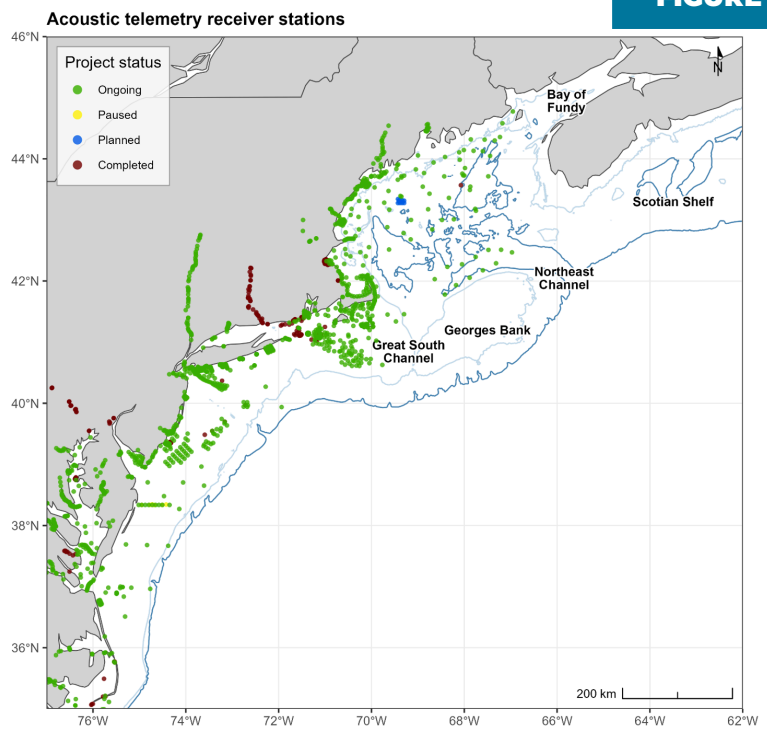


Figure 8. Acoustic telemetry receiver stations across the U.S. mid-Atlantic and Northeast continental shelves (35–46 °N, 77–62 °W) with major features and the 75 m and 200 m isobaths depicted. Stations pooled from the Regional Wildlife Science Collaborative (RWSC), Florida Atlantic Coast Telemetry (FACT), and Atlantic Cooperative Telemetry (ACT) networks. Each point marks one station; color denotes project status at time of retrieval on 2026-06-25 from RWSC (https://rwsc.env.duke.edu/arcgis/rest/services/Fish_and_Sea_Turtle_Tagging/MapServer/0).

5.2 Ongoing Federal Efforts

5.2.1 NOAA Fisheries, Northeast Fisheries Science Center

The Northeast Fisheries Science Center (NEFSC) supports passive and active acoustic monitoring programs. The passive acoustic program at the NEFSC is used to study marine animal soundscapes, movements, and behaviors, as well as how they may be affected by human-generated sounds. There are currently four archival PAM stations in the GoM on the edge of Georges Bank. Each station mooring carries two instruments: a SoundTrap archival recorder for the acoustic data, and a Vemco VR2AR, a combined acoustic release, acoustic-telemetry receiver, and internal temperature logger in a single unit. The SoundTraps acquire continuous recordings, set at a 48 kHz sampling rate with a five month turn around period. The site in Canadian waters also hosts a Full waveform capture POrpoise Detector (F-POD) to detect odontocete clicks. Cetacean detections from these sites can be viewed on the Passive Acoustic Cetacean Map (PACM, https://passiveacoustics.fisheries.noaa.gov/pacm/#/).

NOAA's NEFSC also collects active acoustic data during regular fisheries and ecosystem surveys. The three long-term annual surveys are the bottom trawl survey, the acoustic/midwater-trawl survey, and the Ecosystem Monitoring (EcoMon) survey. The bottom trawl survey is conducted twice a year, in spring and fall, from Cape Hatteras to the Canadian Scotian Shelf, and has been in operation since 1963. Active acoustic data have been collected on these surveys since 1998. Since 2007 the surveys have primarily been conducted aboard the NOAA Ship Henry B. Bigelow, which is equipped with hull-mounted transducers that allow continuous recording. The instruments include a Kongsberg EM2040 multibeam echosounder, a Kongsberg ME70 multibeam echosounder, Kongsberg Simrad split-beam echosounders (the EK500 and EK60, both now deprecated, and the EK80) operating at 18, 38, 70, 120, and 200 kHz depending on the year, and a Teledyne RDI ADCP. The annual acoustic/midwater-trawl survey, also known as the Atlantic Herring Acoustic Survey, was conducted from 1998 to 2012 and collected a diverse suite of information in the GoM. These surveys were conducted each fall in the Georges Bank region, with midwater-trawl sites selected on an ad hoc basis within a systematic design. In addition to the acoustic data, the survey collected discrete biological samples and underwater video footage that supported and validated the continuous active acoustic observations. The EcoMon survey is conducted up to four times per year and collects plankton and ichthyoplankton data using bongo nets, along with oceanographic data, providing information for ecosystem-based management. The active acoustic data are archived and available through NCEI (https://www.ncei.noaa.gov/maps/water-column-sonar/).

5.2.2 NOAA Office of National Marine Sanctuaries, Stellwagen Bank

Similar to the PAM work led by the NEFSC, Stellwagen Bank National Marine Sanctuary (SBNMS) focuses its efforts on observations of underwater sound and how human-generated noise may be impacting marine animals. Within the Sanctuary, SBNMS staff work in collaboration with the NEFSC to operate three archival PAM stations inside the Sanctuary boundary. The easternmost station (SB02) was deployed in 2018 as a national Noise Reference Station (NRS), in collaboration with the National Park Service and the Pacific Marine Environmental Laboratory (PMEL), and serves as a shallow-water reference station for the region. SB01 and SB03 are also located inside the Sanctuary boundary and were deployed in 2018 with a Vemco VR2AR acoustic release and telemetry receiver.

5.2.3 U.S. Geological Survey

The U.S. Geological Survey (USGS) in partnership with WHOI has conducted acoustic surveys in the GoM to characterize seafloor habitat since the 1950s. These early efforts largely focused on broad characterization of the Gulf seafloor (Uchupi, 1965) and on advancing understanding of the region's marine geology and the role of plate tectonics (Emery, 1966). The USGS-WHOI collaboration continued into the early 1970s with an extensive mapping effort using bottom cameras and sediment samples (Schlee, 1973; Folger et al., 1975). Following technological advances in the 1980s, the USGS has mapped the Gulf at high resolution using a combination of techniques, including subbottom profilers, sidescan sonars, and multibeam echosounders. These efforts have continued to evolve, with high-resolution mapping of SBNMS and a partnership with the Massachusetts Office of Coastal Zone Management to map the seafloor of the western GoM.

5.2.4 Office of Naval Research

The Office of Naval Research has supported robust, multidisciplinary research in the shallow-water continental shelf environment of the Gulf of Maine for decades. Efforts have focused on shallow-water acoustic propagation (including the interactions among acoustics, physical oceanography, and the seafloor) to better understand the transmission of sound in a complex coastal ocean; the development of ocean acoustic waveguide remote sensing and passive ocean acoustic waveguide remote sensing for real-time, wide-area sensing; and simultaneous, long-term passive monitoring and modeling of the underwater soundscapes of the Gulf. With a focus on marine mammals, the Gulf of Maine has been an invaluable study area to develop, validate, and test new acoustic hardware, including autonomous PAM systems, acoustic profiling floats, and receiver arrays, as well as software for automated species detection and classification (such as Digital acoustic MONitoring instrument, DMON). Acoustic data collected in this region have also been used to build scientific capacity in the field, serving as key data to examine species ecology and to contribute to training datasets for ongoing advances in processing and analyzing large datasets.

5.3 Ongoing State Efforts

5.3.1 Maine Department of Marine Resources

The Maine Department of Marine Resources (ME DMR) has deployed a network of 26 PAM stations since 2023 in the GoM, eight of which were first deployed in 2020 in collaboration with the NEFSC and the University of Maine (UMaine). These stations are arranged in a coordinated 40 km × 40 km grid, with a mooring generally at the center of each cell. The moorings are hot-swapped every four months, and data are analyzed for North Atlantic right whale (NARW) upcall vocalizations as evidence of NARW presence. ME DMR uses the Ocean Instruments ST600 acoustic recorder at a 48 kHz sampling rate and 16-bit resolution, with a Vemco VR2AR as the acoustic release. Acoustic telemetry detection data are uploaded to the Ocean Tracking Network (OTN). In 2024 and 2025, the state collected high-resolution bathymetry and acoustic backscatter data between the midcoast coastline and the offshore wind research area to fill key information gaps. In early 2026, ME DMR began active acoustic data collection as part of its Habitat Monitoring Program. Active acoustic sampling uses Simrad EK80 split-beam 120 and 200 kHz echosounders, conducted monthly inshore in Maine state waters alongside marine mammal visual surveys, and quarterly offshore around oceanographic and zooplankton sampling stations.

5.3.2 New Hampshire Fish and Game

New Hampshire Fish and Game (NH F&G) deploys one archival SoundTrap PAM station with an acoustic release approximately two miles off the NH coastline near the town of Hampton. The location was coordinated with ME DMR and the Massachusetts Division of Marine Fisheries (MA DMF).

5.3.3 Massachusetts Division of Marine Fisheries

In early 2025, MA DMF Protected Species Program began a PAM project in collaboration with WHOI to detect large whale vocalizations in waters off Massachusetts. The program includes 17 archival bottom-mounted units and two moored near-real-time acoustic monitoring systems. Within the GoM, 11 archival and two real-time units span habitats including Jeffreys Ledge, Massachusetts Bay, Cape Cod Bay, and the eastern outer shore of Cape Cod.



5.4 Ongoing Academic Efforts

5.4.1 The Acoustic and Environmental Observation Network

The Acoustic and Environmental Observation Network (AEON), led by the University of New Hampshire (UNH), was designed to assess the spatial and temporal distribution of the soundscape and link the corresponding directional soundscapes to the ecosystem. Data collection occurs through the use of Acoustic Long Term Observation (ALTO) landers at the following nodes: Northeast Channel (est. Jan 2022-2026), Eastern Coastal Shelf (est. Jan 2022), Georges Basin (est. Jul 2021-2026), Jordan Basin (est. Feb 2021), Wilkinson Basin (est. Feb 2021) and Deep Georges Basin (est. Apr. 2026). Each ALTO lander is equipped with an Autonomous Multichannel Acoustic Recorder (AMAR) sampling at 16 kHz and 512 kHz on a 45-minute-per-hour duty cycle, an Acoustic Zooplankton Fish Profiler (AZFP) or Wideband Autonomous Transceiver (WBAT) echosounder, a Conductivity, Temperature, Optical Dissolved Oxygen (CT-ODO) sensor, and a Vemco fish-tag receiver. These systems are generally serviced annually at which point additional data is collected from the maintenance vessel including Conductivity, Temperature, Depth (CTD) casts, net sampling of zooplankton, and a Fine-Scale Acoustic Survey (FSAS; active hull-mounted echosounder surveys). Metadata observation is accessible at the AEON data portal and data is archived with NCEI. Additionally, a cabled array is being deployed off the Isles of Shoals in summer 2026. The cabled array carries Vemco receivers, a 200 kHz echosounder, redundant CTD/DO/chlorophyll sensors, an ADCP, two acoustic arrays with 1.6 m tetrahedral spacing, and a duty-cycled HD video camera with light.

5.4.2 Robots4Whales

The Robots4Whales program provides near-real-time detections of sei, fin, right, blue, and humpback whales along the east coast of North America. Led by WHOI, this international collaboration draws on numerous partners, with ME DMR, MA DMF, NEFSC, and UMaine participating in the Gulf of Maine region. Detections come from WHOI's Digital acoustic MONitoring instrument (DMON), installed on autonomous platforms such as Slocum gliders and moored buoys and relayed to shore regularly, nominally every two hours. Onshore, trained analysts review them under a formal protocol to determine species presence.

That presence information is shared publicly to raise awareness and to support both NOAA's Slow Zones for Right Whales, a U.S. vessel-strike mitigation program, and the efforts of Transport Canada and Fisheries and Oceans Canada to reduce right whale vessel strikes and fishing gear entanglements in Canadian waters. It reaches stakeholders directly by email and text message, through the Robots4Whales website (robots4whales.whoi.edu), and through several applications, including WhaleMap, Whale Alert, Whale Safe, New York Aquarium, PACM, and Mysticetus. WHOI operates moored buoys at 10 sites along the U.S. east coast, from Savannah, Georgia, to Gloucester, Massachusetts, and together with its collaborators conducts numerous glider missions each year. Within the Gulf of Maine, as of May 2026, this effort comprises two DMON buoys deployed with MA DMF support in Cape Cod Bay and off Cape Ann, several WHOI glider surveys running each summer, fall, and winter with support from NERACOOS and NOAA NEFSC, and occasional glider surveys by UMaine.

5.4.3 Center for Coastal and Ocean Mapping Joint Hydrographic Center

The Center for Coastal and Ocean Mapping / Joint Hydrographic Center (CCOM/JHC), located at UNH in partnership with NOAA, has conducted numerous high-resolution multibeam echosounder surveys and assessments for the GoM. CCOM/JHC published a “Compilation” of multibeam echosounder data for the western GoM and Long Island Sound, integrating data collected by CCOM/JHC and a number of other groups, including NOAA, the USGS, the National Ocean Service, the Gulf of Maine Mapping Initiative, the U.S. Army Corps of Engineers (USACE), and several private institutions (Ward et al., 2020). Drawing on bathymetry, backscatter, and a database of seafloor photos, cores, and roughly 1,000 sediment samples collected by UNH scientists between 1971 and 2023, CCOM/JHC has developed detailed surficial geology maps for the western GoM (Ward et al., 2020). The Compilation and these maps are presently being expanded and updated. Much of this information is available through the CCOM/JHC web portal (https://gis.ccom.unh.edu/portal/home/).



6 OVERVIEW OF OCEAN OBSERVING IN THE REGION

6.1 Federal Ocean Observing Programs

6.1.1 Coastal Data Information Program (CDIP)

Initiated by the U.S. Army Corps of Engineers (USACE) and managed by the Scripps Institution of Oceanography, CDIP is a very focused program in its objectives, data collected, and toolkit. Established to meet the engineering needs of USACE, including the design, construction, and maintenance of coastal infrastructure, CDIP deploys a single type of asset: the Waverider buoy manufactured by Datawell BV Oceanographic Instruments. The primary data collected by these buoys are wave height, period, and direction, with ancillary measurement of sea surface temperature, air temperature, and, on the newest Waverider model, surface current speed and direction. Wave data are critical for engineering decisions, because waves have perhaps the single biggest environmental impact on coastal infrastructure. CDIP's use of a single type of buoy is intended to provide reliable, consistent data in both time and space, including long-term climatologies that characterize the range of conditions a given infrastructure component will face. USACE engineers use data from other ocean observing systems as well, but CDIP stations provide their most important reference points for critical decisions. The selection of CDIP locations and operators, and funding support for each station, can come from USACE itself or from other federal and non-federal partners that see an opportunity to meet their own needs while contributing to the national CDIP network. Perhaps because CDIP focuses on areas where coastal development and infrastructure-maintenance needs are greatest, only two CDIP stations currently operate in the GoM, both in the southwestern corner adjacent to more heavily populated areas: the Cape Cod Buoy southeast of Boston and the Jeffreys Ledge Buoy due east of the New Hampshire Seacoast.

6.1.2 Physical Oceanography Real-Time System (PORTS)

Administered by the NOAA Center for Operational Oceanographic Products and Services, PORTS is similar to CDIP in that it has well-defined priority user groups, primarily port managers, harbormasters, emergency services, and ship captains in busy centers of maritime industry and transportation. To serve these users, PORTS collects a broader array of data than CDIP, but its focal measurements are nevertheless bounded and made with very specific required asset types, including Datawell Waverider buoys. As with CDIP, this specificity of measurements and assets reflects the high level of precision needed for navigation safety in structurally complex, high-traffic settings. Most Waverider buoys operating within the PORTS network are also part of the CDIP network, although the reverse is not true, since not all CDIP stations are close to the maritime centers that PORTS focuses on. In addition to wave data, PORTS collects data on coastal water levels, currents, and weather. Whereas CDIP is structured as a single national network, PORTS operates as a national program made up of tailored systems centered on local maritime areas, though its water level stations together comprise the National Water Level Observation Network. In the GoM, Portsmouth PORTS includes a combined water level and meteorological station and a current meter, both at the mouth of the Piscataqua River. Cape Cod/Buzzards Bay PORTS bridges the GoM and southern New England with a wave buoy at the Cape Cod Bay end of the Cape Cod Canal, a second at the Buzzards Bay end, a current meter within the Canal, and additional meteorological and water level stations outside the GoM at Woods Hole and the Port of New Bedford.

6.1.3 National Data Buoy Center (NDBC)

Housed within the NOAA National Weather Service (NWS), NDBC has specific priority objectives, similar to CDIP and PORTS. The nature of weather forecasting, however, means that NDBC measures a broader array of parameters and, accordingly, adopts a more flexible toolkit. Rather than a single type of buoy, NDBC implements a suite of platforms and sensors tailored to the location and logistics of each station. Its buoys generally measure wind (speed, direction, gusts), atmospheric pressure, air temperature, water temperature, and dew point. However, NDBC stations that are more remote, more costly to maintain, and entail greater power and telemetry challenges may employ a reduced sensor payload. In parallel with its buoy network, NDBC maintains the national Coastal-Marine Automated Network (C-MAN), a series of weather stations mounted on lighthouses, capes, small islands and ledges, and purpose-built towers. NDBC also ingests data from partner observing systems, including CDIP, PORTS, and IOOS assets, into its data management system and data products to facilitate access by NWS forecasters and other users. Stations that meet NDBC standards are assigned an NDBC code number along with the identifier of their primary network. In the GoM and adjacent waters, NDBC operates weather buoys off Boston Harbor, Portland, and Jonesport, and further offshore on Georges Bank and Nantucket Shoals, along with a C-MAN station at Mount Desert Rock near Penobscot Bay.

6.1.4 Integrated Ocean Observing System (IOOS)

The most wide-ranging program in terms of end-users, measurements, assets, and partners, IOOS is a partnership among 17 federal agencies with scientific and policy responsibilities related to the ocean, overseen by a dedicated program office housed within the NOAA National Ocean Service. The program is implemented as an expansive public-private partnership, with 11 Regional Coastal Observing Systems that cover all U.S. coastal, ocean, and Great Lakes waters and are designed and managed by Regional Associations (RAs). Each RA is federally certified by NOAA as a data provider and coordinates a set of implementation partners responsible for different components of the system, including sensors, models, data management infrastructure, and data products. These partners include universities and other research institutions, commercial companies, non-profit organizations, and government agencies. Together, the RAs and their implementation partners generate data and model outputs on 34 IOOS core variables, with the exact mix of measurements, locations, and platforms varying among the 11 regions according to the unique geographic, oceanographic, meteorological, ecological, and socio-economic attributes of each. IOOS RAs support individual CDIP stations, contribute to and/or manage PORTS systems, and push buoy data out to NDBC, ingesting data from all three partner programs into IOOS data management infrastructure and products.

NERACOOS, the IOOS RA covering coastal and ocean areas of the Northeastern U.S., runs a network of oceanographic and ecosystem buoys from Long Island Sound through the GoM. The buoy network is complemented by a high-frequency radar network covering Massachusetts and New Hampshire, a growing network of coastal water level sensors, a regional hindcast and forecast system, and other targeted coastal water quality stations. NERACOOS also supports a *Robots4Whales* winter glider survey in the GoM (see Sect. 7.4.2) and is leading an ongoing project to design and deploy a novel ecosystem buoy within Stellwagen Bank National Marine Sanctuary that will integrate PAM with other priority measurements.

The four federal programs described above focus heavily on meteorological and oceanographic, or "metocean," observations, but observational efforts in the GoM have broadened considerably over time to include biochemical, biological, ecosystem, and cross-disciplinary measurements (e.g., sound and color). With its broad scope and interagency makeup, IOOS has been an important conduit for expanded observation of the GOOS EOVs. These newer efforts, supported by the Marine Biodiversity Observation Network, the Animal Telemetry Network (ATN), and others, are integrated in various ways with the established metocean systems, especially IOOS. This integration lets shared operations and maintenance support multiple assets at once, improving cost-effectiveness, while greater complementarity raises the value of the resulting data. This integrated model offers a template for the GoM's acoustic assets. To date, GoM acoustic assets have not fully coalesced into a single plan or program, nor have they been integrated substantially with other ocean observing systems. However, coordination among implementation partners is increasing, and notable efforts in this direction are underway, improving the prospects for acoustic and other types of ocean observation.

7 CONCLUSIONS AND SUMMARY

Sound is the dominant transporter of information in the ocean, and acoustic methods provide the toolkit to unlock deeper insight into physical oceanography, seafloor structure, biological communities, and human activity alike. Advances in instrumentation, data storage, and computation have dramatically expanded the scale and duration of acoustic observations, especially in the Gulf of Maine region. This growing volume of acoustic data presents a considerable coordination and data management challenge, but also a remarkable opportunity for science, one whose potential for advancing understanding is only just beginning to be realized. This progress will benefit the scientific community, the blue economy, and national security, strengthening maritime safety, coastal preparedness, and ocean health. The Gulf of Maine supports fisheries, maritime shipping, and emerging energy development, and it carries deep economic, cultural, and national security significance. As one of the most dynamic and rapidly changing marine environments on the planet, it demands boundary-pushing science to accurately observe and understand its unique conditions. Beyond tracking those changes, advancing acoustic science will better prepare the region to forecast and adapt to the oceanographic shifts to come.

The goal of GOMRAN is to facilitate and catalyze coordination among implementation partners to achieve transformative science that would be unobtainable by any single program. The process of creating the Science Implementation Plan fostered collaboration and cooperation among federal agencies, state programs, academic institutions, and private organizations. Creating an acoustic network that operates across the spatial and temporal scales at which the Gulf of Maine functions is essential to enhance coordination, build understanding, and enable transformative science. To achieve success, these collaborations will need to continue and be supported by the integration of acoustic data into regional ocean observing systems so that those observations become findable, accessible, interoperable, and reusable (FAIR). The framework for the transformative science of today will also provide the baseline for the research of tomorrow.

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9 APPENDIX A: TOPIC AREA 4 EXPANDED

Included below are the complete list of topics discussed under topic area 4, but were ultimately decided were not relevant, were currently under investigation or were beyond the scope of this project.

Topics identified:

- Biogeochemical changes of the water
- Ghost gear tracking
- Water column stratification
- Sediment transport patterns
- Invasive species monitoring
- Seafloor composition
- Early detection of extreme events, such as heat waves
- Early determination of fisheries closures
- Transition of technology (land to sea)
- Interdisciplinary use of data
- Weather patterns
- Hydrothermal vents (not in GoM)
- Ship speed
- Measuring wake currents of offshore infrastructure



10 APPENDIX B: GOMRAN SIP WORKING GROUPS

During development of the Science Implementation Plan, a subset of participants contributed to two separate rounds of working groups that met outside the main workshops. These groups developed ideas before and after each workshop to generate activities and conversations. **The Science Working Group**, composed of modelers, ocean acousticians, and oceanographers, met in Fall 2024 to generate the four Topic Areas described in this plan. The **Topic Area Working Groups** were four separate groups that met in Spring 2025, each focused on refining and filtering the ideas presented in Workshop 2 for their respective Topic Area. The members listed below participated in at least one meeting of the respective working group. All groups were supported by Jackie Motyka and Caitlin Shanahan.

Members of Science Working Group:

- Dr. Bruce Martin
- Dr. Doug Vandemark
- Dr. Michael Jech
- Dr. Xavier Mouy
- Dr. Jake Kritzer
- Dr. Cameron Thompson
- Dr. Greg Gerbi
- Dr. Jennifer Miksis-Olds
- Dr. Mark Baumgartner
- Dr. Nathan Furey
- Dr. Nick Record
- Dr. Christopher Tremblay
- Dr. Laura Brothers
- Dr. Sofie Van Parijs
- Dr. Anita Murray
- Dr. Ian Jones
- Dr. Sujay Balebail

Members of Topic Area Working Groups:

Topic Area 1: How do local and global environmental changes affect acoustic propagation and soundscapes?

- Dr. Doug Vandemark
- Dr. Elizabeth Weidner
- Dr. Jennifer Miksis-Olds
- Dr. Lauren Freeman

Topic Area 2: How do acoustic measurements serve as an indicator of environmental processes?

- Dr. Cameron Thompson
- Dr. Hannah Blair
- Dr. Jennifer Miksis-Olds
- Dr. Lauren Freeman
- Dr. Michael Jech
- Dr. Sujay Balebail

Topic Area 3: How can hydrographic, biological, and acoustic models be integrated for future prediction?

- Dr. Hannah Blair
- Dr. Lauren Freeman

Topic Area 4: What are we not yet doing with acoustics for oceanographic, environmental, ecological or other scientific work in the GoM that we could utilize acoustics for?

- Dr. Jennifer Miksis-Olds
- Dr. Lauren Freeman
- Dr. Sujay Balebail
- Dr. Anthony Lyons

11 APPENDIX C: GOMRAN SIP WORKSHOP ATTENDEE ORGANIZATION

The GOMRAN SIP plan was crafted over multiple years and assisted by a series of three workshops. Over 70 different individuals were engaged in differing levels. This greater community's institutions are listed below.

The GOMRAN Science Implementation Plan was developed over multiple years through a broad, collaborative effort that included a series of three workshops. More than 70 individuals were engaged at varying levels of involvement. The institutions represented by this broader community are listed below.

Engaged Institutions:

- Applied Ocean Science
- Bigelow Laboratory
- Biodiversity Research Institute
- Bureau of Ocean Energy Management
- College of the Atlantic
- Cornell University
- Dalhousie University
- Fisheries and Oceans Canada
- Eastern Charlotte Waterways Inc
- JASCO
- Maine Department of Marine Resources
- Massachusetts Institute of Technology
- MITRE
- United Stated Navy
- National Centers for Environmental Information
- National Oceanic and Atmospheric Administration
- New England Aquarium
- New Hampshire Fish and Game
- Northeast Fisheries Science Center
- Northeastern Regional Association of Coastal Ocean Observing Systems
- Office of Naval Research
- Ocean Tracking Network

- Portland State University
- Regional Wildlife Science Collaborative
- Stellwagen Bank National Marine Sanctuary
- Stonybrook University
- Syracuse University
- University of Connecticut
- University of Maine
- University of New Brunswick Saint John College
- University of New Hampshire
- United States Geological Survey
- Woods Hole Oceanographic Institution



12 APPENDIX D. ABBREVIATIONS AND ACRONYMS REFERENCE

Abbreviations	Definition
ACT	Atlantic Cooperative Telemetry Network
ADCIRC	Advanced CIRCulation Model
ADCP	Acoustic Doppler Current Profiler
AEON	Acoustic and Environmental Observation Network
AIS	Automatic Identification System
ALTO	Acoustic Long-Term Observation
AMAR	Autonomous Multichannel Acoustic Recorder
AMOC	Atlantic Meridional Overturning Circulation
ATN	Animal Telemetry Network
AZFP	Acoustic Zooplankton Fish Profiler
BOEM	Bureau of Ocean Energy Management
CARE	Center for Acoustics Research and Education
CCOM/JHC	Center for Coastal and Ocean Mapping Joint Hydrographic Center
CDIP	Coastal Data Information Program
C-MAN	Coastal-Marine Automated Network
CO-OPS	NOAA Center for Operational Oceanographic Products and Services
CTD	Conductivity, Temperature, Depth
CT-ODO	Conductivity, Temperature, Optical Dissolved Oxygen
DMON	Digital acoustic MONitoring instrument
DSL	Deep Scattering Layer
EcoMon	Ecosystem Monitoring survey
eDNA	environmental DNA
EEZ	Exclusive Economic Zone
EOVs	Essential Ocean Variables
FACT	Florida Atlantic Coast Telemetry
FAIR	Findable Accessible Interoperable Reusable
F-POD	Full wave-form capture POrpoise Detector
FSAS	Fine-Scale Acoustic Survey
FVCOM	Finite-Volume Community Ocean Model
GoM	Gulf of Maine
GOMRAN	Gulf of Maine Regional Acoustic Network
GOOS	Global Ocean Observing System
HMD	Hybrid Millidecade
HyCOM	Hybrid Coordinate Ocean Model
IOOS	Integrated Ocean Observing System
ISMN	Integrated Sentinel Monitoring Network
LME / LMEs	Large Marine Ecosystem(s)
MA DMF	Massachusetts Division of Marine Fisheries
MBES	Multibeam echosounder
MBON	Marine Biodiversity Observation Network
MCC	Maine Coastal Current
ME DMR	Maine Department of Marine Resources
NARW	North Atlantic Right Whale
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NDBC	National Data Buoy Center
NEFSC	Northeast Fisheries Science Center

Abbreviations	Definition
NECOFS	Northeast Coastal Ocean Forecast System
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NES	Northeast Shelf
NH F&G	New Hampshire Fish and Game
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NROC	Northeast Regional Ocean Council
NRS	Noise Reference Station
NWLON	National Water Level Observation Network
NWS	National Weather Service
OAWRS	Ocean Acoustic Waveguide Remote Sensing
OBIS	Ocean Biodiversity Information System
ONR	Office of Naval Research
OTN	Ocean Tracking Network
PACM	Passive Acoustic Cetacean Map
PAM	Passive Acoustic Monitoring
PMEL	Pacific Marine Environmental Laboratory
POAWRS	Passive Ocean Acoustic Waveguide Remote Sensing
PORTS	Physical Oceanography Real-Time System
RA	Regional Associations
ROMS	Regional Ocean Modeling System
RWSC	Regional Wildlife Science Collaborative
SAV	Submerged aquatic vegetation
SBNMS	Stellwagen Bank National Marine Sanctuary
SoundCoop	Sound Cooperative
Teledyne RDI ADCP	Teledyne RD Instruments Acoustic Doppler Current Profilers
U.S. NES	United States Northeast Shelf
UMaine	University of Maine
UNH	University of New Hampshire
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WBAT	Wide-Band Autonomous Transceiver
WHOI	Woods Hole Oceanographic Institution

