PAPER

NEPAN: A U.S. Northeast Passive Acoustic Sensing Network for Monitoring, Reducing Threats and the Conservation of Marine Animals

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Passive Acoustic Monitoring as a Tool for Research and Management in Marine Ecosystems

ABSTRACT

The U.S. Northeast Passive Acoustic Sensing Network (NEPAN) is composed of numerous passive acoustic recorders that provide archived and near-real-time data on acoustically active marine mammals and fish species. It currently stretches from the northern Gulf of Maine into the New York Bight within the northwest Atlantic Ocean. The recorders include moored units that are entirely subsurface and archive audio, units with real-time reporting capabilities via surface buoys, and autonomous vehicles or "gliders." Data derived from NEPAN will provide long-term year-round information on the presence and spatial distribution of vocal mysticetes and odontocetes, as well as fish. These data will be used to address critical conservation and management needs as well as to reduce threats from anthropogenic activities. Currently, NEPAN will operate from 2014 until late 2017. This listening network is an example of how collaborative scientific efforts and financial investment across many federal agencies can produce a novel far-reaching solution to current scientific information gaps. In this article, we lay out our vision for the future and provide details on the technologies and applications currently used in NEPAN. Furthermore, we present a road map that includes expanding the range of NEPAN throughout the Western North Atlantic Ocean, detecting more species and addressing an even more diverse range of management and conservation applications. However, the reality remains that the continued operation and/or expansion of this type of "listening network" will only be possible in the long term with clear and direct support from the National Oceanic and Atmospheric Administration (NOAA).

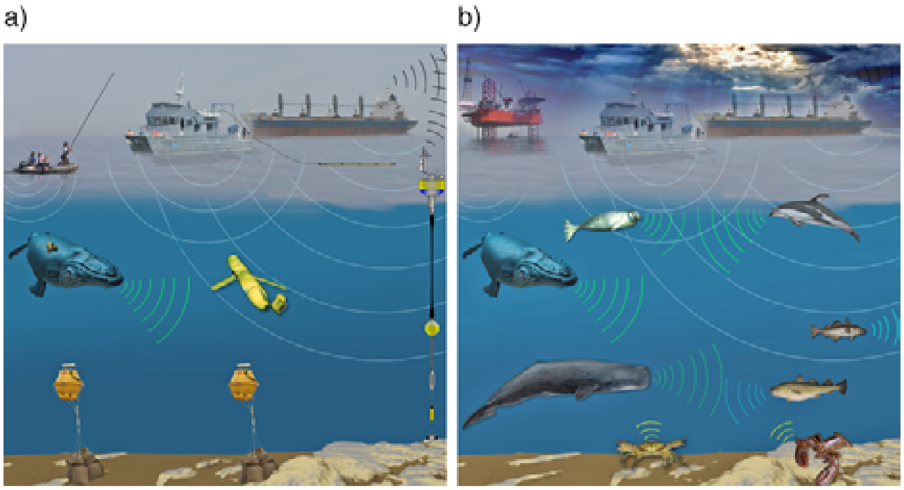
Keywords: passive acoustic recorders, autonomous vehicles, monitoring, mitigation, reducing threats

Increasing anthropogenic activities in our oceans and their subsequent impacts on marine ecosystems are clear conservation issues of national and global concern. Habitat degradation and the indirect impacts on marine vertebrates from activities associated with oil and gas exploration, renewable energy development, and shipping or fisheries operations threaten marine ecosystem health (Kappel, 2005; Halpern et al., 2007; Read, 2008; Davidson et al., 2012; Rolland et al., 2012). Efficient and cost-effective means to assess species distribution, abundance, and exposure to anthropogenic impacts are critical to the conservation of those species and their habitat. The mission of some federal agencies, such as National Oceanic and Atmospheric Administration (NOAA) in the United States, includes the conservation and recovery of depleted or endangered marine species, in accordance with the Marine Mammal Protection Act and the Endangered Species Act. Essential to these mandates is an adequate understanding of marine animal abundance, population trends, and seasonal occurrence, as well as an assessment of sources of risks associated with human activities. Among these risks are the effects of underwater noise introduced by human activities on marine animal acoustic communication, hearing and behavior, and the direct interactions of individual animals with fisheries and shipping operations (Cholewiak, Risch et al., 2013).

Sound propagates more readily and over greater distances through water than light. Given this and the fact that light is limited at depth, sound is the primary modality of choice for marine animal communication, foraging, and navigation. Many marine species are highly vocal and much of their social, reproductive, and foraging behavior is acoustically mediated. Studies of the vocalizations that these animals emit—although completely reliant on the animals actually vocalizing—can provide information on their occurrence, distribution, relative abundance, and habitat use (e.g., Moore et al., 2006; Van Parijs et al., 2009; Širović & Hildebrand, 2011; Van Opzeeland et al., 2013a; Risch et al., 2014). In the past decade, passive acoustic approaches for studying marine animal populations have seen a rapid expansion in both the tools available and the geographic scope in which studies have been conducted. Substantial improvements in the capabilities, availability, and price of acoustic recorders now provide a suite of cost-effective options for researchers to characterize the acoustic ecology of many species. They also provide means to quantify human-introduced noise levels in continuous records gathered in broad areas and over long periods. Recording devices include (a) fixed bottom-mounted acoustic recorders (BMARs) that can record up to several years in a single deployment, (b) hydrophone arrays towed behind survey vessels, (c) acoustic tags that record individual animal calls, (d) autonomous underwater vehicles (such as gliders) and unmanned surface vehicles (capable of navigating along assigned routes) or (e) anchored surface buoys that transmit underwater acoustic data to a land-based location in near real-time (Figure 1a). Hardware

FIGURE 1

(a) This image depicts the range of passive acoustic technologies currently available for collecting data. These include bottom-mounted archival marine acoustic recorders, acoustic recording tags deployed on animals, acoustic arrays towed behind survey vessels and autonomous underwater vehicles or gliders, as well as surface-mounted buoys that report back data in near real time. (b) This image depicts the possible "soundscape" of an ocean habitat composed of sound contributions from invertebrates, fish, marine mammals, weather events, and anthropogenic sources such as vessels. Long-term measurements of changes in soundscapes, such as the decrease in biological or increase in anthropogenic sound sources, will enable the relative "acoustic health" of a habitat to be monitored.



and software refinements now allow data collection in remote areas and detection of species that are difficult to observe using aircraft- or vessel-based visual surveys.

Emerging theoretical methodologies applied to passive acoustic data provide novel ways to address large-scale ecological and behavioral questions. For example, using acoustic indices to monitor biodiversity and species richness (Fay, 2009; McWilliam & Hawkins, 2013; Staaterman et al., 2013; Staaterman & Paris, 2014), modeling loss of "communication space" (i.e., the space over which the sounds of an animal can be heard by conspecifics, or a listening animal can hear sounds of conspecifics) (Clark et al., 2009; Hatch et al., 2012; Williams et al., 2014), and integrating visual data with passively obtained acoustic data to increase the value of each technique (Thompson et al., 2014).

Studies of marine mammals, especially cetaceans, have traditionally been conducted visually, from either vessel or aerial platforms. However, visual surveys are limited by daylight and weather conditions, as well as the short amount of time that marine mammals spend at the surface and are therefore detectable (e.g., Clark et al., 2010). Unconstrained by visual detection limitations, passive acoustic studies consistently provide a far richer characterization of marine mammal occurrence and habitat use information beyond seasons and regions where visual surveys previously documented them (e.g., Vu et al., 2012; Van Opzeeland et al., 2013b; Širović et al., 2014). Such passive acoustic studies highlight the need to transition to techniques that more completely characterize the actual distribution, occurrence, and relative abundance of marine mammals.

Recent passive acoustic studies have also been used to identify spawning fish stocks, map their distribution, and define their seasonal occurrence and long-term persistence (Hernandez et al., 2013; Wall et al., 2012). Combined with active acoustic technology (i.e., in this case active acoustics refers to the high-frequency pinging sound produced by tags implanted in individual mature fish), which provides detailed information on behavior, movement patterns, sex ratios, and site fidelity of fish populations (Dean et al., 2012, 2014; Zemeckis et al., 2014a, 2014b, 2014c), this blended approach offers a novel direction for fisheries management and the conservation of fish stocks.

Consequently, the use of passive acoustic methods to describe animal distribution, occurrence, abundance, and behavior is increasingly being recognized as tools not only for basic research but also with clear monitoring roles that substantially improve our capacity to inform conservation strategies. These are conservation and monitoring strategies that undoubtedly further the mission of NOAA and those of its partner agencies.

NOAA's Current Involvement in Passive Acoustic Research and Development

Within NOAA, passive acoustic research has steadily grown in importance as a valued technique for improving and modernizing the collection of biological and anthropogenic data. NOAA Fisheries' Offices of Science and Technology and Protected Resources and the National Ocean Service's Office of National Marine Sanctuaries are currently finalizing an agency-wide Ocean Noise Strategy that aims to guide NOAA's science and management decisions toward a longer-term vision for addressing noise impacts to marine life (http://cetsound.noaa.gov). The Strategy highlights three major areas: (1) the importance of sound use and hearing for a diverse array of NOAA-managed species, (2) the importance of acoustic habitat in supporting NOAA's management of these species, and (3) the data collection, tools, and approaches necessary to characterize soundscapes (e.g., Figure 1b) in order to support species- and habitat-based management approaches. The Northeast Passive Acoustic Sensing Network (NEPAN) is a premier example of how to go about collecting data to inform the Strategy in a broad reaching manner.

NOAA's Northeast Regional Passive Acoustic Research

At NOAA's Northeast Fisheries Science Center (NEFSC), the Passive Acoustic Research Program's primary focus is collecting passive acoustic data throughout the western North Atlantic Ocean using a variety of the fixed and mobile platforms identified above. Our work—along with research partners at the Stellwagen Bank National Marine Sanctuary (SBNMS) and regular collaborative interactions with National Marine Fisheries Service (NMFS) science centers and headquarters and academia—combines long-term monitoring of marine species to understand their distribution, abundance and ecology, and quantification of anthropogenic noise threats with research focusing on monitoring the soundscapes of various key habitats in our region. Ultimately, our aim is to support broad marine management and conservation strategies throughout NOAA as part of a larger network of scientists conducting passive acoustic research.

A Vision for a Comprehensive Passive Acoustic Sensing Network

We envision a passive acoustic monitoring network positioned over the continental shelf and upper continental slope off the East Coast of the United States that will employ archival and near real-time passive acoustic systems to meet pressing NOAA management needs. The network would include both fixed and mobile assets that could monitor marine mammals, soniferous fish and ocean noise over both short (days to weeks) and long (months to years) time scales. Some of these assets would be deployed in sensitive or industrial areas, such as wind farm construction sites, shipping lanes, heavily fished areas, or marine reserves, while others would cover broad spatial scales to inform questions about species' ranges, migration routes, or presence in unexpected locations. Ideally, some network assets would be collocated with oceanographic observatories (e.g., Northeast Regional Association of Coastal and Ocean Observing Systems buoys [http://www.neracoos.org], U.S. Integrated Observing System Pioneer array [http://www.whoi.edu/ooi_cgsn/pioneer-array]) to enable research on the influence of environmental variability on marine mammal and fish occurrence. Near-real-time reporting of acoustic detections would improve the efficiency of visual surveys and on-water research efforts by providing notice of species' presence, as well as enable adaptive management efforts, such as ship speed reductions, ship re-routing, fishing exclusions, or reduction of marine construction activities. For the many monitoring needs that do not require an immediate response to acoustic detections (e.g., to assess long-term changes in occurrence with climate change or defining migration corridors), the network would include archival passive acoustic recorders. These data would be used to inform NMFS stock assessment reports, permit consultations, and specific management actions. In addition both approaches would drive the development of new methods for integrating data from different platforms to achieve the best understanding of what each data stream has to offer. NEPAN presents the first steps to fulfilling this vision.

Monitoring and Reducing Threats to Marine Animals: Where, When, and What?

Long-term data sets are needed to allow an understanding of animal movements, distribution, and behavior, which may change with oceanographic, climatic, and anthropogenic pressures. In particular, acoustic monitoring is capable of addressing a range of information needs, including the following: Where is a given species in space? When and for how long is it in a given area? What is its broad behavioral category and in some specific cases how many animals are there? To assess threats, acoustic information can help determine if the organism is in the area that overlaps with a potentially harmful anthropogenic sound source or activity and if its group size or behavior will be disrupted.

Historically, NOAA's NMFS has run regular vessel or aerial surveys to collect visual data of species distribution and occurrence. Visual approaches are excellent methods for collecting information on individual identity and group size but are constrained by weather, daylight, cost, and safety concerns. In contrast, passive acoustic technology is able to provide long-term records of species presence, site usage, relative density, and behavior regardless of weather or light condition. Combining these approaches offers an opportunity to make more informed decisions. By evaluating and combining the relative strengths of both approaches, and the quality of the data collected, the money spent, and the scope of where and how data are collected can be significantly improved.

In this manuscript, we demonstrate how NOAA's NEFSC Passive Acoustic Research Program, together with the technological and analytical support of the Woods Hole Oceanographic Institute (WHOI) and the federal groups highlighted above, is engaged in the process of creating the technological infrastructure to establish NEPAN to address long-term monitoring and mitigation need for endangered marine mammals and fish.

NEPAN—The U.S. Northeast Passive Acoustic Sensing Network's Current Structure and Composition

Northeast Regions of Interest

The Gulf of Maine (GOM) is a unique marine environment located off the shores of southeastern Canada and coastal New England (Figure 2). This area is one of the most biologically productive ecosystems in the world and is home to a diverse array of marine microorganisms, plants, and marine animals. The GOM is often referred to as the "sea within a sea," as it is a semienclosed area bounded to the south and east by large underwater banks. The presence and features of Georges Bank, part of the continental shelf, greatly impact the characteristics and productivity of the GOM, which is more greatly influenced by the colder waters of the Labrador Current from the north than the Gulf Stream waters to the south. Therefore, the waters of the GOM are more nutrient-rich than more southern waters, an important factor that helped sustain this area as a historical fishing ground over the centuries. Additionally, these combined oceanographic and topographic features seasonally attract marine animals into the areas highlighted in NEPAN such as Massachusetts Bay and the SBNMS (Figure 2) (Clapham et al., 1993; Morano et al., 2012a). Knowing how and when endangered mysticetes use these areas and where Atlantic cod form spawning aggregations are critical information needs given NOAA's aim to protect and return species to healthy numbers.

The New York Bight (NYB) is located to the south of the GOM. It consists largely of continental shelf and includes the Hudson Canyon (Figure 2). In contrast to the GOM, the coastal climate of the bight is temperate as a result of direct contact from the Gulf Stream. The NYB appears to be a pivotal point used by northward migrating marine mammals before they turn and head east and north across or around Georges Bank (Risch et al., 2014; Schlesinger & Bonacci, 2014) or west into Massachusetts Bay. Which species passes through the NYB area and how long they remain is not well known. The GOM and the NYB are transected by major shipping channels that access Boston and New York Harbors, with both channels crossing areas that have seasonally high marine mammal densities (e.g., Morano et al., 2012b; Mussoline et al., 2012; Vu et al., 2012).

Species of Interest

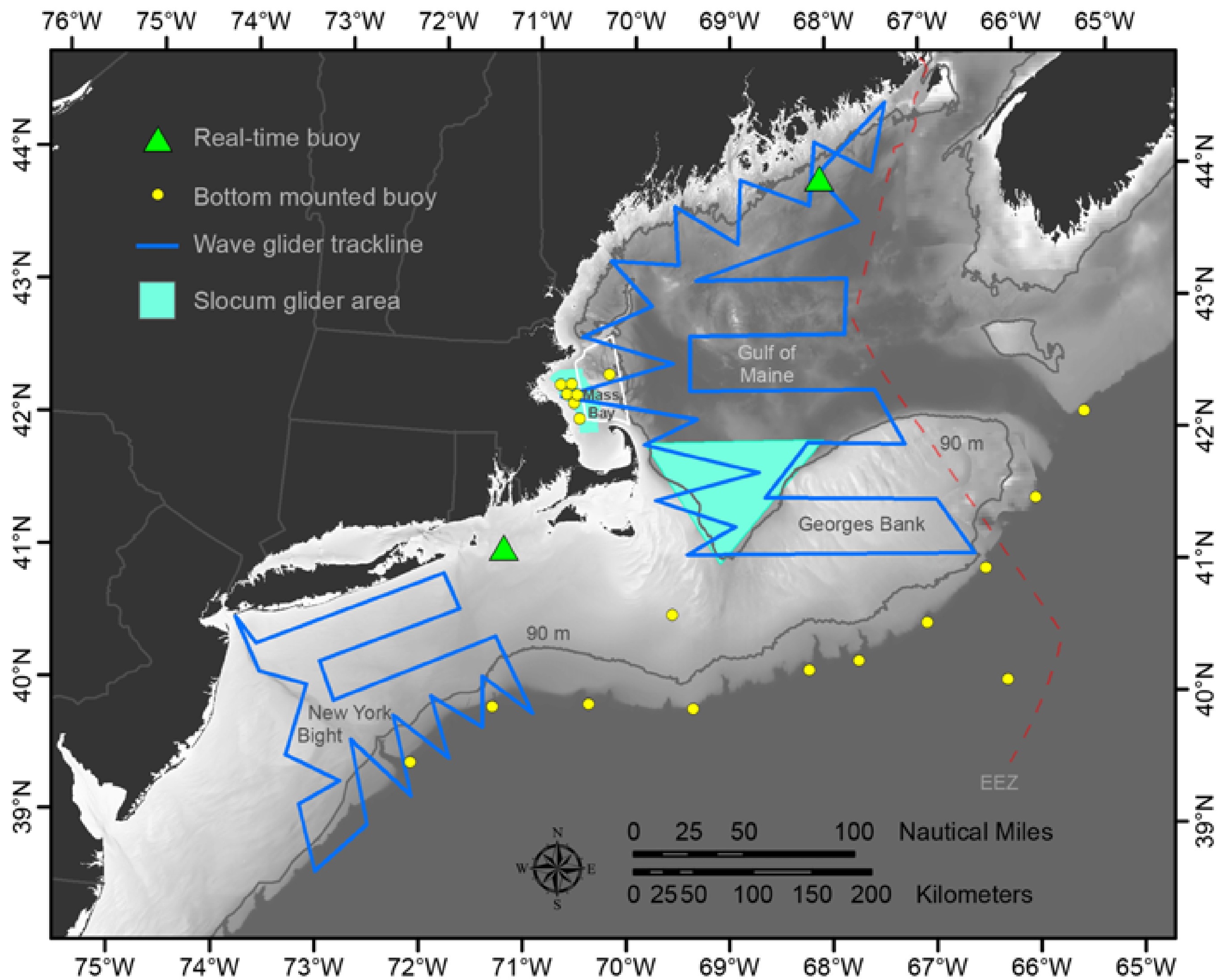
Large Whales

Six of eight populations of large whales (the North Atlantic right whale, *Eubalaena glacialis*; the humpback whale, *Megaptera novaeangliae*; the sei whale, *Balaenoptera borealis*; the fin whale, *B. physalus*; the blue whale, *B. m. musculus*; and the sperm whale, *Physeter macrocephalus*) in the western North Atlantic are endangered or of special concern under existing U.S. and Canadian legislation (Van Der Hoop et al., 2013). Many of these managed populations have not recovered (Fujiwara & Caswell, 2001; Clapham et al., 1999) and have high mortality rates, especially from vessel strikes and entanglement in fishing gear (Volgenau et al., 1995; Laist et al., 2001). The North Atlantic right whale is of particular concern due to its low population size, currently estimated at around 500 individuals, and urban coastal distribution (Mate et al., 1997; Kraus et al., 2005). It is important to note that, other than for the North Atlantic right whale, very little is still known about any of these species despite decades of protection.

The GOM inshore waters are known to be important feeding grounds for all North Atlantic baleen whale species (Agler et al., 1993; Waring et al., 2007; Baumgartner & Fratantoni, 2008), and within this region, there is high site fidelity, with whales returning repeatedly to areas such as Cape Cod Bay, Georges Bank, the Great South Channel, and the SBNMS. The NYB and Rhode Island Sound are less well known; however, the same baleen whale species are consistently re-sighted using these areas (Schlesinger & Bonacci, 2014). How species use these areas is a question this acoustic project will help to answer. Mysticetes are thought to use these areas for socializing and to bring their calves on the way to more northern feeding grounds. Some odonotocetes, such as the sperm whale, are deep-diving

FIGURE 2

A map of the U.S. Northeast Passive Acoustic sensing Network (NEPAN) depicting the estimated locations of sensors, areas of operation, and track lines for monitoring marine animals, in particular North Atlantic right, fin, sei, humpback, blue, sperm, and beaked whales in addition to Atlantic cod. The dotted red line indicates the boundary of the U.S. EEZ. Various components of this network will be in place from 2014 through 2017. The passive acoustic technologies currently part of the NEPAN are moored buoys, autonomous Slocum electric and wave gliders, all of which report data in near real time, in addition to bottom-mounted archival recording buoys, each of which is discussed below. (Color versions of figures are available online at: http://www.ingentaconnect.com/content/mts/mtsj/2015/00000049/00000002.)



whales and inhabit the shelf-break areas off the northeast coastline and deeper waters (Waring et al., 2001). Sperm whales are thought to first move north to Georges Bank and then continue further north in the summer time from more southerly areas (Waring et al., 2008).

All marine mammals are acoustically active, and their species-specific call types can be used to identify the presence of and (in some instances) can provide a measure of relative abundance of a species (Barlow & Taylor, 2005; Marques et al., 2009, 2013; Martin et al., 2013). In some cases, enough information exists to determine or infer the behavioral context of the calls including foraging, socializing, or reproductive behavior. Mysticetes use a range of low-frequency sounds that can travel over many kilometers for communication (e.g., Payne & Webb, 1971; Clark & Gagnon, 2004; Newhall et al., 2012; Weirathmueller et al., 2013), while in contrast, signals of odontocetes travel less far underwater. Sperm or beaked whales and delphinids use higher-frequency clicks and whistles for finding their prey, navigation, and social behavior. These differences in the frequency ranges over which mysticetes and odonotocetes call results in the need to use different recording equipment or sampling parameters and subsequently requires a different set of analytical software and research skills to identify and interpret.

North Atlantic Cod

North Atlantic cod (*Gadus morhua*) is a demersal predatory fish that has been targeted by both commercial and recreational fisheries for centuries (Lear, 1998). In the northwest Atlantic, cod was heavily overfished throughout its range, resulting in a crash in several U.S. and Canadian stocks during the early 1990s (Serchuk & Wigley, 1992; Fogarty & Murawski, 1998; Frank et al., 2011). In the Canadian Scotian Shelf ecosystem, abundances of predator and prey species appear to be reverting to pre-reversal levels (Frank et al., 2011). In contrast, cod stocks continue to be of considerable concern in U.S. waters. Research into the spawning behavior of this species can help inform conservation and management measures aimed at increasing stocks to healthy levels. Male cod produce grunts that are low-frequency broad band signals ranging between 50 and 100 Hz during courtship and spawning. As a result, passive acoustic monitoring offers a novel perspective from which to investigate the occurrence, spatial extent, and duration of spawning cod aggregations (Hernandez et al., 2013). Therefore, Atlantic cod conservation has been added as a primary objective within NEPAN, with the intention of expanding this approach to other fish species in the future. This project integrates information obtained on cod grunts from passive acoustic recordings with active acoustic data derived from tagged individuals (Armstrong et al., 2013; Dean et al., 2014; Zemeckis et al., 2014a, 2014b, 2014c). This work is carried out in collaboration with the Massachusetts Division of Marine Fisheries (MASS DMF) SBNMS, the School for Marine Science and Technology (SMAST), and The Nature Conservancy. Our aim is to provide information that will help put in place time and space closures relevant to this species in order to aid its recovery.

NEPAN Technical Objectives

Our objective in creating NEPAN is to demonstrate an operational capability of autonomous acoustic platforms to conduct long-term, large-scale archival and near-real-time monitoring for endangered marine mammals and fish species from the GOM to the NYB area. A suite of acoustic platforms will be employed to achieve comprehensive monitoring over a variety of spatial (ones to hundreds of kilometers) and temporal scales (from hours to years) (Table 1). Our project seeks to (1) conduct and demonstrate the value of year-round, large-scale acoustic monitoring; (2) validate near real-time acoustic detections of endangered mysticetes with airplane-, ship-, and land-based visual observations from NOAA supported platforms; and (3) develop best practices for integrating near real-time and archival acoustic detections into persistent visual monitoring programs, such as the NOAA aerial survey program off the U.S. Eastern seaboard. In addition, we will demonstrate how passive acoustic technologies can be used to help reduce threats to marine animals through cooperative efforts such as monitoring done in conjunction with the Coast Guard activities mentioned below.

NEPAN Technology Description

Passive Acoustic Archival Recordings

NEPAN incorporates a variety of BMARs, which require the retrieval of the unit and post-processing of the data before information on species acoustic occurrence can be obtained. Multiple types of BMAR are being used as part of NEPAN; included here are three examples. First, for targeting low-frequency mysticetes and fish, we are using the Cornell University Marine Autonomous Recording Unit, the MARU or "pop up" (Calupca et al., 2000), which we typically configure to record continuously at a sampling rate of 2 kHz for up to 6 months. Second, we are using NOAA's Pacific Marine Environmental Laboratories (PMEL) recorders (configured to record for up to 2 years at sampling rate of 2 kHz), also for monitoring low-frequency species and ambient noise (Fox et al., 2001; Mellinger et al., 2007b). Finally, we are using the JASCO Applied Science's Autonomous Multichannel Acoustic Recorder (AMAR, JASCO Applied Sciences, Halifax, NS, Canada) to target both low-frequency species and higher-frequency odontocetes such as sperm and beaked whales (configured to record 12 months of duty cycled data). These types of passive acoustic recorders have a proven track record for studying marine mammals and fish (Stafford et al., 1999, 2001; Nieukirk et al., 2004; Mellinger et al., 2007a; Mellinger et al., 2011; Van Opzeeland et al., 2010; Klinck et al., 2012; Charif et al., 2013; Delarue et al., 2014).

Near Real-Time Passive Acoustic Detection

NEPAN will make use of newly developed technology to provide species occurrence information from passive acoustics in near real time. Detection,

TABLE 1

The characteristics of each autonomous platform, including appropriate space/time scales, mobility, and reporting interval for real-time passive acoustic detection data of North Atlantic right whales, sei, fin, and humpback whales (i.e. how often detection and classification data are transmitted from the platform to a shore-side computer).

Platform	Spatial Scale	Temporal Scale	Mobility	Reporting Interval (h)
Slocum glider	10 s to 100 s km	1–3 months	Mobile (navigated)	2
Wave glider	100 s to 1,000 s km	Months–years	Mobile (navigated)	2
Surface moored buoy	10 s m to 10 s km	Months-years	Stationary	2
Bottom moored buoy	10 s m to 10 s km	6 months–2 years	Stationary	Archival data

classification, and near-real-time reporting of baleen whale calls have been demonstrated by Baumgartner et al. (2013, 2014) using the low-frequency detection and classification system (LFDCS; Baumgartner & Mussoline, 2011; briefly described below) on the digital acoustic monitoring (DMON) instrument (Johnson & Hurst, 2007) installed in a Slocum glider (Teledyne Webb Research, Inc.). The DMON/LFDCS is capable of recording low-frequency audio (continuous or duty-cycled), detecting, characterizing, and classifying the calls of right, humpback, fin, and sei whales, and relaying detection and classification data to the platform to which it is attached. In addition to the Slocum glider, WHOI has integrated the DMON/LFDCS into a wave glider (Liquid Robotics, Inc.) and a moored buoy (EOM Offshore). These platforms transmit summary and detailed detection data generated by the DMON/LFDCS to a shore-side server via Iridium satellite where it is immediately posted to a Website (http://dcs.whoi.edu).

Both Slocum and wave gliders are vehicles that can be autonomously navigated simply by providing way-points while they are at sea via Iridium satellite communications. The Slocum glider moves up and down in the water column using a buoyancy pump and moves laterally using lift generated by two short wings (Rudnick et al., 2004). Because it moves up and down, it can collect profiles of environmental data (e.g., temperature, salinity, chlorophyll fluorescence) together with passive acoustic data. The wave glider consists of a surface float (resembling a surfboard) and a tethered “sub” that use the energy of surface waves to provide propulsion; solar-charged batteries provide power for the navigation system, instrumentation, and Iridium modem (Wilcox et al., 2009). The Slocum glider's endurance is limited by battery capacity (from a few weeks to 1–3 months on alkaline or lithium batteries, respectively), whereas the endurance of the wave glider is theoretically unlimited.

The DMON-equipped moored buoy consists of an anchor, acoustic release, subsurface float, a “stretch hose,” and a surface buoy. The hose, which contains helically wound electromagnetic conductors, can stretch to nearly twice its relaxed length and is thus capable of decoupling the motions of the surface buoy from the mooring line below the subsurface float; this ensures a quiet acoustic environment for passive acoustic monitoring. The DMON is attached to the mooring line below the subsurface float, and detection data are relayed to the surface buoy from the DMON via electromagnetic cable and the conductors in the stretch hose. A data logger in the buoy continuously collects and stores these data and eventually transmits them to a shore-side computer via an Iridium satellite modem on a predetermined schedule (e.g., once every hour).

The near-real-time reporting capabilities of gliders and moored buoys will facilitate directed visual surveys as well as the development of adaptive management strategies to reduce the interactions between human activities and marine animals. Archival acoustic recorders will provide continuous data in discrete locations for ocean noise monitoring and evaluating long-term patterns in habitat use by individual species of both marine mammals and fish. Beyond species occurrence, this approach also opens the opportunity for long-term assessment of habitat health through the evaluation and monitoring of the soundscape in sensitive or biologically important areas.

Passive Acoustic Analyses

Baleen whale calls will be detected and classified in archived data collected as part of NEPAN using the LFDCS developed by M. Baumgartner. This system uses dynamic programming to estimate a pitch track for each call and then classifies features extracted from the pitch track using quadratic discriminant function analysis. Classification relies on a call library of known species-specific call types. Call types have been built for right, sei, fin, and humpback whales in the GOM (Baumgartner & Mussoline, 2011; Baumgartner et al., 2013) and for bowhead, fin, and beluga whales, as well as bearded seals and walrus in the Arctic (Baumgartner et al., 2014). New call types for blue whales are under development. Higher-frequency data will be analyzed using custom-built click detectors written in Matlab for extracting beaked and sperm whale clicks. The output from these detectors will be verified manually. Currently, the LFDCS does not extract Atlantic cod grunts; however, an Atlantic cod grunt detector now exists for the Atlantic cod research component of NEPAN (Urazghildiiev & Van Parijs, submitted). In the interim, our analytical approach has been to subsample the data at time frames that are relevant to extracting information on seasonal and diel occurrence of spawning cod (see Hernandez et al., 2013, for an example). An additional benefit to passive acoustic recordings is that these same data records can be investigated for other soniferous fish species, such as haddock, *Melanogrammus aeglefinus*, at a later date as the acoustic repertoires of these species become better known.

NEPAN Technologies Operating in 2015–2017

Wider GOM

A wave glider equipped with the DMON/LFDCS will be deployed during 2015 to conduct continuous broad scale surveys throughout the GOM west of the Exclusive Economic Zone (EEZ) for ~1.5 years (Figure 2; Table 2). The proposed survey track for the GOM region is designed to sample both across the southward-moving coastal current on the northern and western fringes of the GOM using a zig-zag design and along a straight-track design throughout the central GOM where surface currents are more quiescent. Surveying continuously at a nominal speed of 1.5 knots, the glider will complete the 2700-km circuit in 41 days. However, the glider may be commanded to remain in areas of interest based on the near real-time whale detection information. To complement the large-scale survey conducted by the wave glider, smaller-scale surveys (tens of kilometers) will be conducted with a DMON/LFDCS-equipped Slocum glider in the Great South Channel of the southern GOM during May of 2015 and 2016 (Figure 2). This region was chosen based on the predictable availability of mysticetes and our ability to conduct sustained visual observations near the glider during an annual NOAA NEFSC spring survey. A moored DMON/LFDCS buoy will also be installed in the waters immediately adjacent to Mount Desert Rock, Maine, during early 2015 where fin and humpback whales are commonly encountered, and it will remain in operation for 2 years (Figure 2).

Throughout the duration of NEPAN around 60 archival BMARs will be deployed throughout the GOM ranging from 6 months to 2 years in duration, depending on the objective and recorder type. Archived passive acoustic data will be reviewed upon retrieval of the BMARs. These efforts are aimed at improving our understanding of the long-term presence, seasonal occurrence and behavior of endangered mysticetes and, in some cases, odontocetes in key areas of their habitat.

Massachusetts Bay

Within the GOM, there are two additional areas where smaller-scale efforts are ongoing in Massachusetts Bay (Figure 2). The first focuses on Atlantic cod conservation. The current paucity of Atlantic cod in their historical spawning areas presents a challenge to identifying and managing appropriate spawning areas and seasons. Within NEPAN, six archival BMARs, part of the effort mentioned above, will be deployed over a 6-month period (October to March in both 2015 and 2016) in historical and putative spawning areas and seasons to monitor the presence or absence of spawning grunts throughout the Winter Cod Conservation Zone (WCCZ) and federal waters adjacent to this area. In conjunction with passive acoustic efforts, our partners (MASS DMF and SMAST) will instrument mature cod with active acoustic tags that send signals to underwater Vemco receivers (http://Vemco.com) that allows their movements, behavior, and site fidelity to be monitored. Thirty to 40 Vemco receivers will be deployed both with BMARs and alone to cover as large an area as possible. Two Slocum gliders instrumented with a recording DMON and an acoustic Vemco receiver will listen for the presence of cod vocalizations and the actively pinging tags. In addition, acoustic telemetry data received from other acoustically tagged fish species, such as Atlantic sturgeon, *Acipenser oxyrinchus*, recorded on these receivers will be shared with relevant NOAA

TABLE 2

This table includes detailed information on the individual projects that together form the Northeast Passive Acoustic Sensing Network (NEPAN). For each individual project, the table shows the time span over which passive acoustic data are being collected, the region of operation, the target marine species, the acoustic technology used (and the funding agency supporting each project). The funding agencies are abbreviated in the table as follows: The U.S. Department of Energy, Bureau of Ocean Energy Management (BOEM), the U.S. Department of Defense's Environmental Security Technology Certification Program (ESTCP), the U.S. Navy's Living Marine Resources Program (LMR), the Naval Operations Energy and Environmental Readiness Division (N45), the NOAA Ocean Acoustics Program, Saltonstall-Kennedy program and Office of Protected Research (OPR), NOAA's National Marine Fisheries Research Co-operative Program and the U.S. Coast Guard.

Time Span	Northeast U.S. Region	Target Species	Acoustic Technology	Funding Agency/Entity
2014–2017	Gulf of Maine (GOM)/New York Bight (NYB)	North Atlantic right (NARW), fin, sei, humpback, and blue whale	Cornell University bottom-mounted archival Marine Acoustic Recording Units (MARUs)	BOEM/N45
2014–2016	Off Georges Bank, GOM	Long-term ambient noise records of all marine species	National Oceanic and Atmospheric Administration, (NOAA) /Pacific Marine Environmental Laboratories (PMEL) bottom-mounted archival acoustic recorder (Noise Recording Station (NRS)08)	NOAA Ocean Acoustics Program
2014–2015	Browns Bank, GOM	NARW, fin, sei, humpback, blue, and minke whales	NOAA/PMEL Fixed archival acoustic recorder	NOAA Ocean Acoustics Program
2014–2015	Georges Bank, GOM	NARW, fin, sei, humpback, blue and minke, beaked, and sperm whales	JASCO Applied Sciences Ltd. Fixed archival Autonomous Multichannel Acoustic Recorder (AMAR)	BOEM/N45
2014–2016	Massachusetts Bay, GOM	Atlantic Cod	Cornell University MARUs, Teledyne Webb Research Slocum gliders, DMON recorder, and VEMCOVEMCO tags and receivers	NOAA Saltonstall-Kennedy/NMFS Co-op research
2014–2016	Stellwagen Bank National Marine Sanctuary, GOM	Long-term ambient noise records of all marine species	NOAA/PMEL Fixed archival acoustic recorder (NRS09)	NOAA Ocean Acoustics Program
2015–2017	Rhode Island Sound	NARW, fin, sei, humpback	Near real-time EOM Offshore surface moored buoy with DMON/LFDCS	U.S. Coast Guard
2015–2017	Mount Desert Rock, GOM	NARW, fin, sei, humpback	Near-real-time EOM Offshore surface moored buoy with DMON/LFDCS	ESTCP & LMR
2015–2017	Great South Channel, GOM	NARW, fin, sei, humpback	Near real-time Teledyne Webb Research Slocum glider with DMON/LFDCS	ESTCP & LMR
2015–2017	GOM	NARW, fin, sei, humpback	Near real time Liquid Robotics wave glider with DMON/LFDCS	ESTCP & LMR
2015–2016	NYB	NARW, fin, sei, humpback	Near real-time Liquid Robotics wave glider with DMON/LFDCS	NOAA OPR

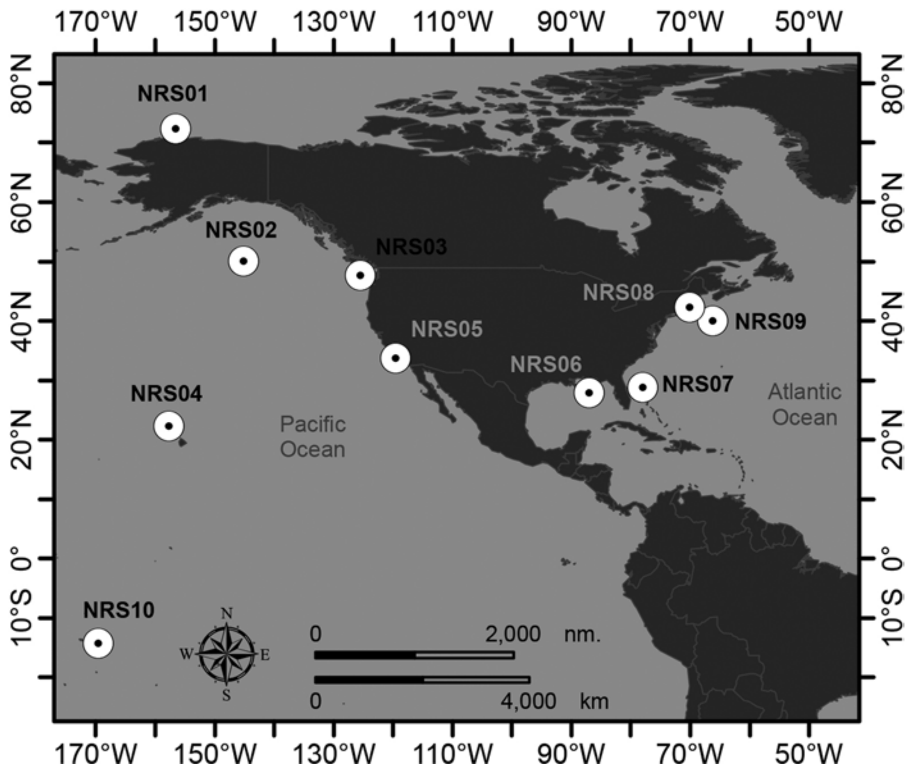
colleagues. The aim of the glider is to locate the presence of actively spawning cod over a larger spatial area than our fixed passive acoustic and active acoustic sensors can monitor. These combined approaches aim to identify the current status of cod in this historic spawning area and highlight any areas that still persist and would benefit from conservation measures such as fisheries closures.

Stellwagen Bank National Marine Sanctuary

The second smaller-scale effort is within the SBNMS. NOAA's NEFSC Passive Acoustic Research Program was set up in 2006 through a partnership with colleagues at the National Marine Sanctuaries' (NMS) SBNMS. The current research focus of this partnership has matured toward monitoring long-term changes and trends in the underwater ambient sound fields of SBNMS's soundscape, primarily using the NOAA-operated network of ocean noise reference stations (NRS; http://www.nefsc.noaa.gov/psb/acoustics/psbAcousticsNRS.html). The NRS project currently involves a coordinated deployment of 10 NOAA PMEL low-frequency (sampling rate = 5,000 Hz with low-pass filter to give a usable range of 10–2,200 Hz) passive acoustic recorders throughout U.S. waters (Figure 3). Of these, three are within NMS, and two recorders, NRS 08 and NRS 09, are part of NEPAN.

FIGURE 3

The 10 locations of the NOAA-operated network of Noise Reference Stations (NRS) aimed at monitoring long-term changes and trends in the underwater ambient sound fields.



NYB and Rhode Island Sound Areas

A wave glider will carry out continuous large-scale acoustic surveys within the NYB area using DMON/LFDCS monitoring technology starting in 2015. This wave glider is intended to operate in conjunction with concurrent aerial surveys and archival bottom-mounted recorders managed by New York State Department of Environmental Conservation (DEC). A DMON/LFDCS moored buoy will also be deployed in Rhode Island Sound in early 2015 for real-time monitoring of baleen whale presence to help the U.S. Coast Guard manage their activities in offshore gunnery ranges and, in particular, to reduce threats posed by those activities to endangered North Atlantic right whales. Throughout the duration of NEPAN around 20 archival BMARs will be deployed, in the NY Bight covering the primary shipping lanes out to the shelf break to monitor year round for the presence of mysticetes (Figure 2; Table 2), with oversight from DEC.

Validation of Acoustic Detections

It is critical to build confidence in estimates of species occurrence generated by both archival and near real-time passive acoustic platforms if these estimates are to be used for management efforts. For this reason, significant effort has been included in the NEPAN science plan to validate passive acoustic detections. Two stages of evaluation will be conducted: acoustic analysis and visual analysis. Acoustic analysis will compare manually reviewed archived audio with automated detections generated in near real-time by the DMON/LFDCS or during post-recovery processing of archival recorders (note that the DMON/LFDCS records either continuous or duty-cycled audio to enable this acoustic analysis). Performance metrics, such as false detection and missed call rates, can be determined from this acoustic analysis.

A Road Map for the Future

A Unique Network and Approach

Few broadly geographically spaced passive acoustic sensing network such as the NEPAN, with the focus on collecting multispecies marine animal information, exist in the world. Other large-scale passive acoustic efforts or observatories exist. Examples of some of these are the Alfred Wegner Institute's "Perennial Acoustic Observatory in the Antarctic Ocean" sensors, which live stream continuous underwater sounds from a single location in Antarctica (e.g., Boebel et al., 2006, 2008; Van Opzeeland et al., 2008; Klinck et al., 2010); the European-based "Listening to the Deep" project (http://www.listentothedeep.com/) that allows you to listen online to a wide number of moored acoustic sensors recording across Europe, Asia, and North America; the European ESONET NoE project (http://www.esonet-noe.org/); the Australian Integrated Marine Observing System (IMOS) (http://cmst.curtin.edu.au/research/imos.cfm); and the Canadian Ocean networks (http://www.oceannetworks.ca/). Where NEPAN differs substantially from these other networks in that its core goals are directly focused on integrating passive acoustic information in monitoring and conservation actions. The aim of NEPAN is not just to monitor using passive acoustics in both real time and through archival means but also to use the data collected to inform NOAA's mandates, such as the NMFS stock assessments and the Ocean Noise Strategy, in addition to permitting, environmental impact assessment, and other relevant consultations resulting in management decisions that affect the study species. In addition, NEPAN aims to be at the forefront of the discussion and development of new scientific methodologies for interpreting and merging different data platforms, such as visual and acoustic data. NOAA's current management frameworks do not always reflect the best way forward for managing marine life in our increasingly industrial oceans. It is important for scientists within and outside the agency to formulate new approaches that may be more effective and directly focused on marine conservation.

NEPAN is a premier example of how passive acoustic data collection can be integrated among agencies, regions, and platforms to meet core monitoring and management needs within NOAA. The data derived from the NEPAN will provide information on the occurrence of mysticetes and fish throughout large areas of the GOM and NYB across seasons for multiple years.

The value of receiving near-real-time information on species presence has already been demonstrated in areas where the risk of ship strike is high for North Atlantic right whales (listenforwhales.org; Spaulding et al., 2009). The NEPAN highlights additional applications, such as reducing the risk of interactions between the U.S. Coast Guard gunnery activities and North Atlantic right whales, through strategic placement of a fixed passive acoustic mooring that will report detections of right whale, in addition to fin, sei, and humpback whale vocalizations. Lastly this approach can also provide evidence to support further research and initiate new management actions, such as the establishment of closures based on the acoustic detection of cod spawning grounds.

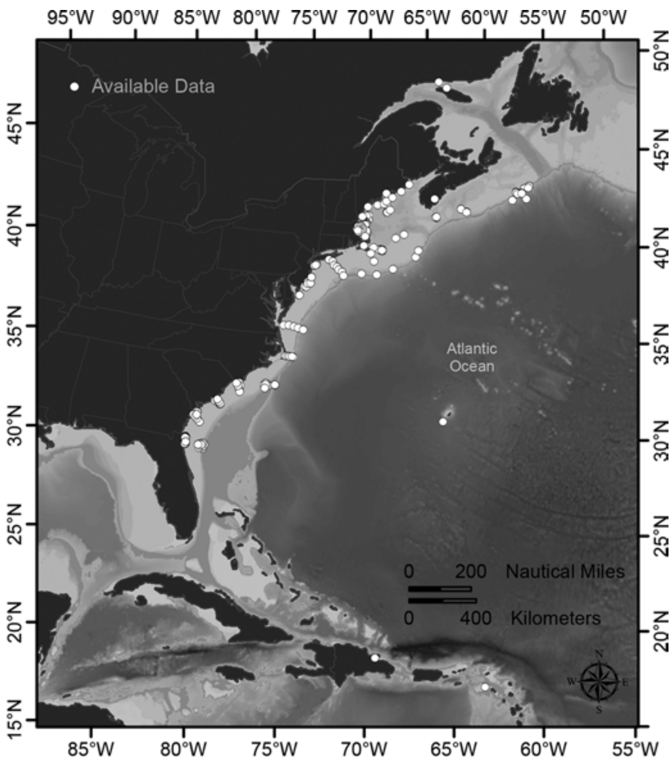
Expanding NEPAN: Integration With Other Passive Acoustic Monitoring Efforts

Marine animals are not bound by state or regional boundaries and move across ocean basins and along coastal shores of the entire western North Atlantic Ocean (Waring et al., 2008; Mellinger et al., 2011; Nieukirk et al., 2012). The NEPAN will provide data to integrate with other passive acoustic monitoring efforts that are being conducted in both U.S. and Canadian waters. One such project is the Western Atlantic Passive Acoustics analysis of mysticetes (WAPAW), a focused study that is utilizing existing archival acoustic data from recorders previously deployed along the western North Atlantic continental shelf area (Figure 4).

This study is being undertaken by NOAA's NEFSC with the collaborative input of individuals, institutions, and government agencies engaged in passive acoustic research in this region. WAPAW aims to use one single methodological approach to better understand the presence, distribution, and migration routes of North Atlantic right, humpback, sei, fin, and blue whales across the entire Western Atlantic seaboard. Additionally, NEPAN will work together with the Canadian MEOPAR network (Marine Environment Observation Prediction and Response network), which includes within its scope a project aimed at developing real-time reporting capabilities to alert ship captains to the presence of mysticetes in Canadian waters. Lastly, NOAA's NEFSC and Southeast Fisheries Science Center in collaboration with Duke University and Scripps Institution of Oceanography

FIGURE 4

A map of the locations of the majority of low-frequency (5 kHz or less) passive acoustic recordings that were made throughout the Western North Atlantic continental shelf area from 2002 to 2014 by a range of individuals, institutions, and government agencies. The Western Atlantic Passive Acoustics analysis of mysticetes (WAPAW) is a focused study that is utilizing the existing data that were made available to carry out a cohesive analysis across all data holdings for the presence of mysticetes.



are starting a new effort aimed at monitoring 10 sites along the Western Atlantic shelf break region to understand the occurrence of marine species prior to the commencement of oil and gas exploration in the western Atlantic Ocean.

In the light of upcoming climatic and anthropogenic challenges, combining efforts across platforms and regions is crucial for monitoring ocean health. The development of a mature passive acoustic network will better inform which regions and areas are most likely of biological or anthropogenic importance to the monitoring, management and conservation goals of NOAA.

Investment in Innovative Technologies and Approaches

Recognition is growing in U.S. regional and federal governments that passive acoustic research is a vital component of future management strategies and directions. However, even though NOAA has clear directives to recover depleted species direct investment in passive acoustic research and infrastructure from NOAA is lacking, as no base funding exists for these efforts. The funding that supports the work mentioned in this manuscript comes from a variety of competitive research grants, various programs within the U.S. Department of Defense and the U.S. Department of Energy, Bureau of Ocean Energy Management (BOEM), the Department of Defense's Environmental Security Technology Certification Program (ESTCP), the U.S. Navy's Living Marine Resources program (LMR) and the Naval Operations Energy and Environmental Readiness Division (N45), with some funding provided by the NOAA Ocean Acoustics Program and the NOAA Office of Protected Resources (Table 2).

With the current expansion of renewable energy and the impending start of offshore oil and gas exploration on the U.S. East Coast, it is imperative that NOAA supports the collection of data on marine animals at larger scales, both spatial and temporal, that are relevant to the species that occur there and activities that are planned. Projects such as NEPAN must be maintained over the long term to collect data on a time scale relevant to ecological variability and anthropogenic threats. NOAA is interested in investing in novel technologies but must improve its ability to address current mandates with baseline instrumentation. Building a long-term passive acoustic network such as this one described here will require more than an innovative approach to finding funds; it will require clear directed support from within the agency. In this light, it is also NOAA's responsibility to invest in the long-term development and maintenance of passive acoustic technologies within the agency.

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