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NOAA and BOEM Minimum Recommendations for Use of Passive Acoustic Listening Systems in Offshore Wind Energy Development Monitoring and Mitigation Programs

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Offshore wind energy development is rapidly ramping up in United States (U.S.) waters in order to meet renewable energy goals. With a diverse suite of endangered large whale species and a multitude of other protected marine species frequenting these same waters, understanding the potential consequences of construction and operation activities is essential to advancing responsible offshore wind development. Passive acoustic monitoring (PAM) represents a newer technology that has become one of several methods of choice for monitoring trends in the presence of species, the soundscape, mitigating risk, and evaluating potential behavioral and distributional changes resulting from offshore wind activities. Federal and State regulators, the offshore wind industry, and environmental advocates require detailed information on PAM capabilities and techniques needed to promote efficient, consistent, and meaningful data collection efforts on local and regional scales. PAM during offshore wind construction and operation may be required by the National Oceanic and Atmospheric Administration and Bureau of Ocean Energy Management through project-related permits and approvals issued pursuant to relevant statutes and regulations. The recommendations in this paper aim to support this need as well as to aid the development of project-specific PAM Plans by identifying minimum procedures, system requirements, and other important components for inclusion, while promoting consistency across plans. These recommendations provide an initial guide for stakeholders to meet the rapid development of the offshore wind industry in United States waters. Approaches to PAM and agency requirements will evolve as future permits are issued and construction plans are approved, regional research priorities are refined, and scientific publications and new technologies become available.

Keywords: passive acoustic monitoring, offshore wind energy, baleen whales, recommendations, marine mammal monitoring and mitigation

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INTRODUCTION

Rapid global economic growth has contributed to today's increasing demand for energy. The development of alternative renewable and clean energy sources, such as solar, wind, and hydrogen energy, has become a priority as countries seek to expand their use of renewable energy sources and meet goals to reduce greenhouse gas emissions (Leung and Yang, 2012). Among these many renewable resources, offshore wind energy development offers rapidly evolving technological approaches, promising commercial prospects, and large-scale electricity generation such as in Europe. The speed and manner in which many coastal nations pursue offshore renewable energy development has varied dramatically in the past (Portman et al., 2009), and the United States (U.S.) is now poised to rapidly develop offshore wind leases throughout the Atlantic Outer Continental Shelf (OCS), as well as the Pacific and Gulf of Mexico.

A recent White House statement announced that in order to position the domestic offshore wind industry to meet its target of deploying 30 gigawatts of offshore wind by 2030, the Department of the Interior's Bureau of Ocean Energy Management (BOEM) plans to advance new lease sales and complete review of at least 16 Construction and Operations Plans (COPs) by 2025, representing more than 19 GW of new clean energy (Office of the Press Secretary, 2021). The main environmental concerns related to offshore wind development for marine animals are primarily focused around construction and operations through increased noise levels, behavioral changes, displacement from important biological areas such as feeding grounds, risk of vessel collisions, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments (e.g., Tougaard et al., 2009; Bailey et al., 2014).

The potential effects of offshore wind energy on protected marine species are regulated primarily by National Oceanic and Atmospheric Administration (NOAA) under the Endangered Species Act, Marine Mammal Protection Act, National Environmental Policy Act, National Marine Sanctuary Act, and the Energy Policy Act and by BOEM through issuance of leases and approval of COPs. During activities where potential adverse effects may occur to marine species, including marine mammals, a combination of visual surveying and passive acoustic monitoring (PAM) may be required to record information on species presence and behavior to inform BOEM and NOAA mitigation requirements measures aimed at minimizing potential effects. PAM may also be required during operations to record ambient noise levels and to monitor noise impacts on marine species. In addition, PAM is a proven method for monitoring calling species to gain ecological context before, during, and after offshore wind development activities (site characterization, construction, operations, and decommissioning).

The inclusion of PAM alongside visual data collection is valuable to provide the most accurate record of species presence as possible. In the case of data collection for mitigation, visual observers will add to the detection probability of the species of interest, which is ideal when aiming for a 100% detection rate. While in the case of data collection for monitoring visual surveys, PAM can be seen as orthogonal and complementary methods. PAM provides long continuous time series with low spatial resolution, while visual surveys provide snapshots with low temporal resolution but high spatial resolution. Just as visual observations can be limited by poor weather and light conditions, PAM systems also have limitations, such as when animals are not calling. Visual and PAM approaches are well understood to provide best results when combined together (e.g., Barlow and Taylor, 2005; Clark et al., 2010; Gerrodette et al., 2011). However, in these recommendations we just focus on the applications and uses of PAM.

Passive acoustic monitoring encompasses a functional suite of technologies that can answer scientific questions and inform management and/or mitigation decisions over long temporal and large spatial scales (Rountree et al., 2006; Van Parijs et al., 2009, 2015; Marques et al., 2013; Gibb et al., 2019). The tools that are available to acquire and analyze passive acoustic data have undergone a revolutionary change over the last couple of decades and have substantially increased our ability to both collect extensive time series and apply PAM as a functional management tool (e.g., Mellinger et al., 2007; Luczkovich et al., 2008; Van Opzeeland et al., 2008; Zimmer, 2011; Sugai et al., 2019; Desjonquères et al., 2020). PAM platforms include moored recording buoys, autonomous underwater or surface vehicles (Autonomous Underwater Vehicles/Autonomous Underwater Vehicles), profile drifters, and towed hydrophone arrays (**Figure 1**), which can be strategically located to provide real-time information for immediate mitigative decision-making, monitor or assess the effects from specific activities, and gather continuous archival recordings for long-term monitoring, periodic evaluation, and adaptive management (Van Parijs and Southall, 2007; Van Parijs et al., 2009). PAM allows a broad spectrum of data to be collected, including all calling marine animal species within recording range, different call types, distributions and occupancy, individual calling locations, and abundance of some species, as well as anthropogenic and other natural sounds, collectively known as an underwater "soundscape" (e.g., Van Parijs et al., 2009; Marques et al., 2013; Mooney et al., 2013; Baumgartner et al., 2018; **Figure 2**).

Although our primary focus is on marine mammal mitigation and monitoring for offshore wind applications, the PAM techniques mentioned here can also be used to characterize soundscapes, monitor ambient noise levels, and provide essential information on other soniferous species such as fishes (e.g., Zemeckis et al., 2019; Caiger et al., 2020). As offshore wind development expands across regions, PAM data can increase in utility when collected in a standardized method and analyzed using similar techniques. Given the value of PAM data, especially for future permit requests, authorizations, and research, these recommendations also contain information on standardizing data collection methods, processing and analyses, archiving acoustic recordings, and data products, as well as steps to making these products publicly available. Several previous workshops have started the discussion to improve standards for PAM data collection, data analyses, and archiving (BOEM, 2018; Gulka and Williams, 2018; Kraus et al., 2019; POWER-US, 2019; NYSERDA, 2020; BOEM, 2021; WCS, 2021), and standards are increasingly

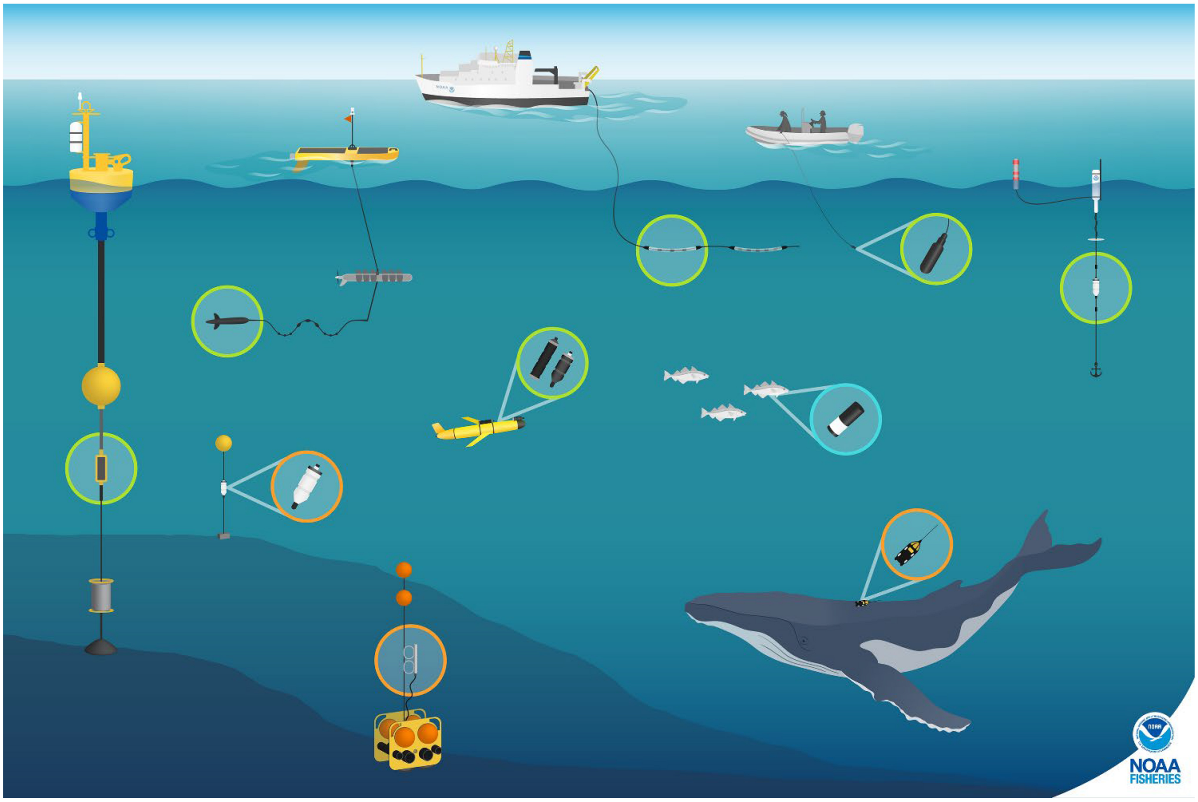

FIGURE 1 | The illustration shows examples of different types of acoustic technologies. From left to right, the illustration shows a moored surface buoy, wave glider, SoundTrap on the seafloor, bottom-mounted acoustic recorder (High-frequency Acoustic Recording Package [HARP]), Slocum glider, NOAA ship towing a hydrophone array, tagged Atlantic cod, humpback whale with an archival tag, drop hydrophone deployed from a small boat, and autonomous, free-floating acoustic recorder (Drifting Acoustic Spar Buoy Recorder [DASBR]). The different technologies are highlighted with colored circles that show a zoomed-in view of the instruments and colors that represent the type of data collected: green for real-time data capabilities, orange for archival data, and blue for active acoustics.

being documented in the Oceans Best Practices Repository[1]. Our recommendations build on these previous efforts.

Project-specific PAM Plans, developed by project proponents and approved by Federal agencies, should include descriptions of equipment, procedures (deployment, retrieval, detection, and analyses), ISO data quality standards and protocols that will be used for monitoring and mitigation. In the United States, PAM specifications for inclusion in a PAM Plan will need to be developed in consultation with NOAA and other permitting agencies, such as BOEM. To design a PAM Plan, the following six topics need to be included and addressed: species of interest, PAM system types, PAM recording technologies, PAM study design, PAM system requirements, and PAM data archiving and reporting.

PAM PLAN STEPS

Species of Interest

Prior to designing any PAM Plan, it is essential to identify and understand the acoustic frequency ranges of the sound sources that are of interest and in need of monitoring (**Figure 3**). Unlike in southern North Sea waters, where only a handful of marine mammal species require consideration, most United States waters are frequented by a large number of protected species (Jefferson et al., 2011). In the case of the Atlantic OCS, where offshore wind energy development will initially occur, the primary baleen whale (mysticetes) species of concern include: North Atlantic right whales (North Atlantic right whales; *Eubalaena glacialis*), humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*), fin whales (*Balaenoptera physalus*), blue whales (*Balaenoptera musculus*), and sei whales (*Balaenoptera borealis*). These species are low-frequency sound producers (i.e., most of the acoustic energy is below 1 kilohertz [kHz]), and therefore all PAM recording technologies, PAM system requirements, and PAM designs need to be constructed with these frequency requirements and specific call types in mind (**Table 1**). Other species of interest for this region are the higher frequency producing toothed whale (odontocetes) species, such as sperm whales (*Physeter macrocephalus*), beaked whales (Ziphiidae), pilot whales (*Globicephala* spp.), dolphins (Delphinidae), and ultra-high-frequency harbor porpoises (*Phocoena phocoena*). The frequency ranges for these species and the need for additional

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[1] https://www.oceanbestpractices.org

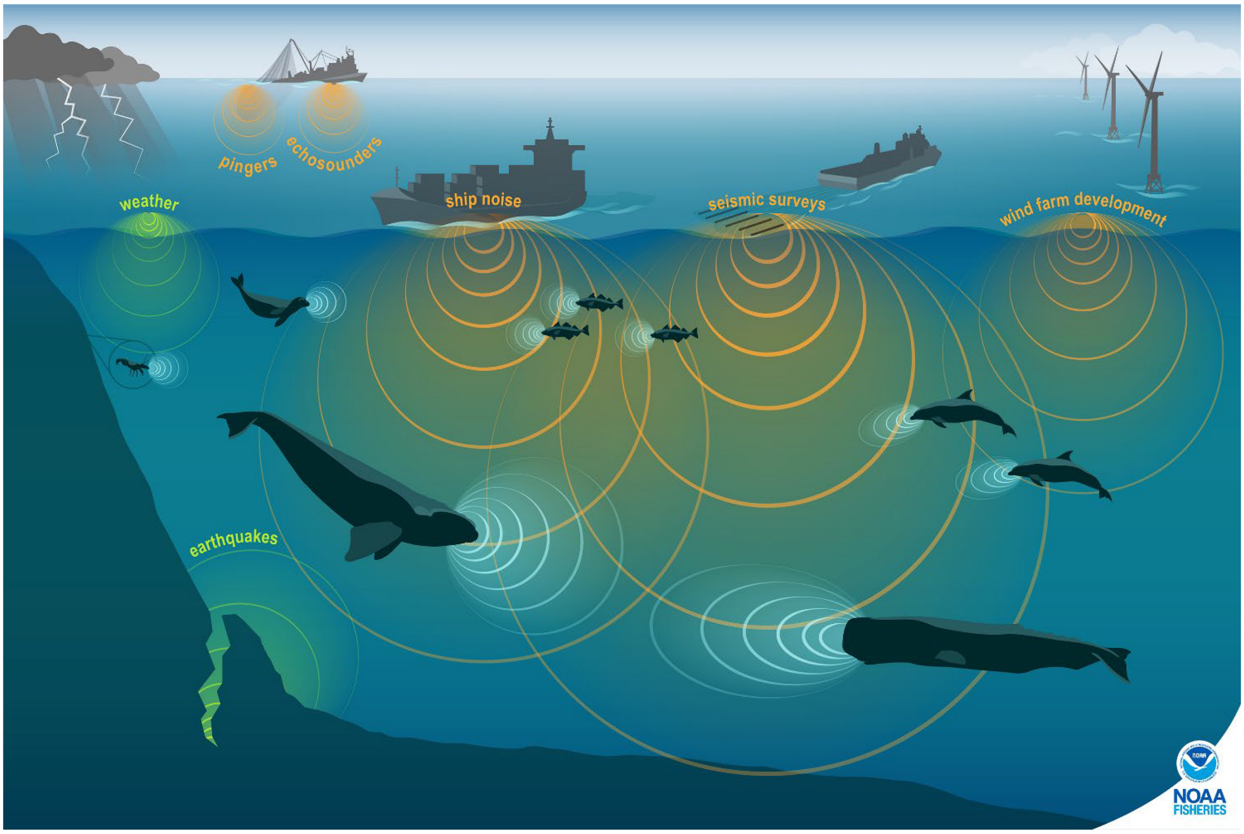

FIGURE 2 | This conceptual illustration shows images of anthropogenic (human-created), biological (marine animal), and abiotic (environmental) sources of sound and approximately proportional sound waves, making up an ocean soundscape. The sound sources include weather, earthquakes, snapping shrimp, harbor seal, Atlantic cod, right whale, sperm whale, common dolphins, fishing vessel, shipping vessel, seismic survey ship, and wind farm development. The sound waves are represented by overlapping colored circles that indicate the type of sounds: human-made sounds are orange, animal sounds are light blue, and environmental sounds are light green. The circles increase in size to show the approximate magnitude of sound waves and distances noise travels underwater.

PAM recording technology, PAM system requirements and PAM design needs to be considered when creating a PAM Plan (**Table 2**). Additional species of interest are acoustically active fishes or invertebrates, for which a combination of PAM and acoustic telemetry can be used to delineate the temporal and spatial extent of spawning grounds (e.g., Ingram et al., 2019; Zemeckis et al., 2019). Fish are generally low-frequency sound producers with most species' core frequency occurring below 1 kHz (**Figure 3**).

PAM System Types

Here, we divide the PAM approaches into two different system types of data collection, archival and real-time data collection (**Figure 1**). Both the scientific objectives and the specifications for data management differ depending on the data collection methods. These approaches may have distinct applications for either mitigation or long-term monitoring, or have utility for both applications.

Archival PAM Systems

Archival PAM recordings are primarily used for long-term monitoring, with capabilities for recording durations ranging from several weeks up to several years (Sousa-lima et al., 2013). Continuous recordings provide an uninterrupted record of species' acoustic presence, allowing investigators to evaluate species distribution and occurrence, and changes in animal calls, which provide information on behavioral state (e.g., foraging, reproduction, socializing) in a given area or region. In addition they allow for the evaluation of seasonal, inter and intra annual variation in species presence and occurrence over time. Alternatively, recordings can be duty-cycled (defined as the fraction of time that a PAM system is actively recording) to maximize recording duration at sea while limiting equipment interactions (e.g., retrieval to swap out hard drives or batteries). Duty-cycled data is less preferred, as inevitably some information is lost, and biases are introduced by using a reduced recording schedule. If the duty-cycle listening period and recording interval are not appropriately matched to the duration and timing of animal calls, potential detections may be missed and species occurrence underestimated (Miksis-Olds et al., 2010; Sousa-lima et al., 2013; Thomisch et al., 2015; Stanistreet et al., 2016). For example, in Thomisch et al. (2015), duty-cycling at 50 and 2% showed a decrease in accuracy in both acoustic presence and call rate estimates. If it is necessary to duty-cycle, frequent and

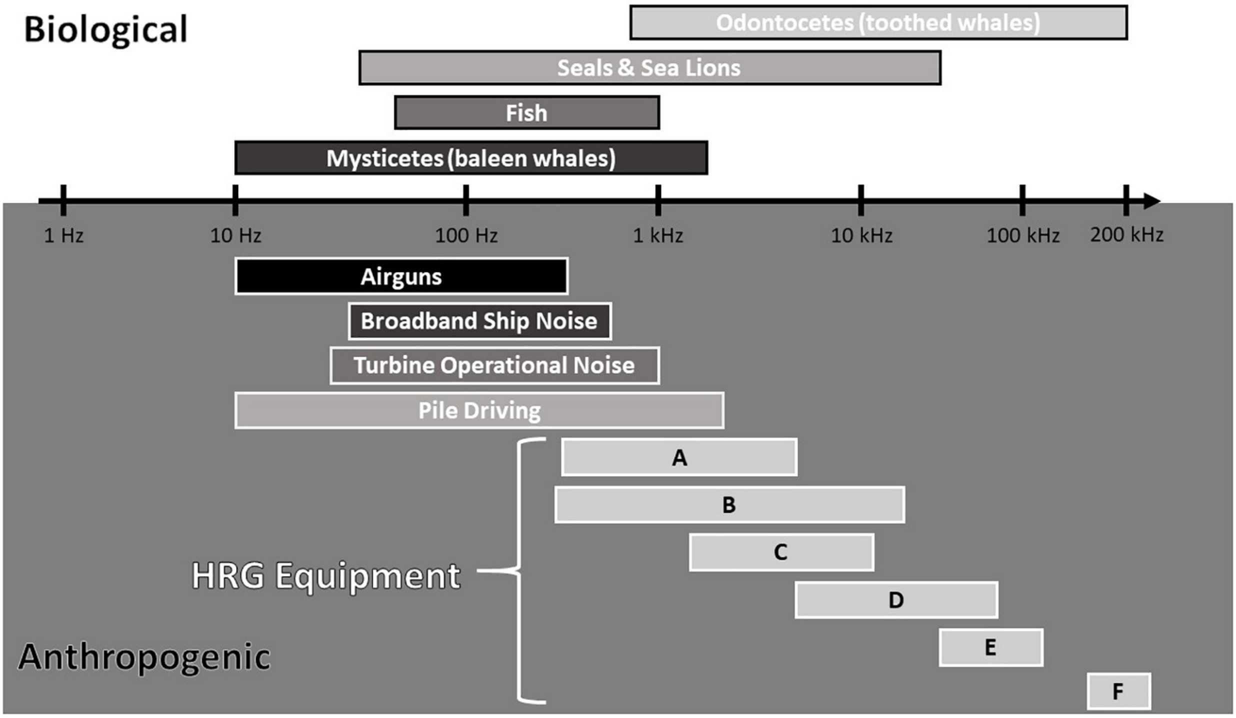

FIGURE 3 | This figure shows the frequency ranges over which groups of marine animals call (top) and the primary frequency ranges over which some anthropogenic sound sources (bottom) overlap. The frequency scale is on a logarithmic scale, expanding from 1 to 200,000 Hz. Mysticetes (baleen whales), such as the North Atlantic right whale, fin, sei, blue, humpback, and minke whale, produce low-frequency sounds, while odontocetes (toothed whales), such as the sperm whale, produce higher frequency sounds. Anthropogenic sound sources and primary frequency ranges are displayed on the bottom of the figure, with the bracketed boxes corresponding to the following high resolution geophysical (HRG) equipment sound sources: (A) Sparkers/boomers; (B) Non-parametric sub-bottom profilers; (C) Acoustic corers; (D) Acoustic positioning systems; (E) Parametric sub-bottom profilers; (F) Multibeam echosounders and sidescan sonar.

TABLE 1 | A list of the primary baleen whale species found along the Atlantic Outer Continental Shelf and their primary call type, call frequency range, and core detection bandwidth.

Species (North Atlantic)	Main Call Types (primary behavioral function)	Min Frequency (Hz)	Max Frequency (Hz)	Core Detection Bandwidth (Hz)	References
North Atlantic right whale	Upcall (social)	30	1,000	65–400	Parks and Tyack, 2005, Clark et al., 2007, Parks et al., 2011, Davis et al., 2017
	Gunshot (reproductive)	20	22,000	36–891	Parks et al., 2005, Cholewiak et al., 2018
Blue whale	Song (reproductive) and Arch calls (foraging)	9	70	15–20	Mellinger and Clark, 2003, Berchok et al., 2006
Humpback whale	Song (reproductive) and Social (social)	40	4,000	80–1,500	Winn and Winn, 1978, Kowarski et al., 2019
Fin whale	20 Hz Pulses (reproductive)	18	80	20	Watkins, 1981, Delarue et al., 2009
Minke whale	Pulse Trains (reproductive and social)	50	400	50–400	Risch et al., 2013, 2014
Sei whale	Downsweeps (reproductive and social)	30	90	34–82	Baumgartner et al., 2008, Tremblay et al., 2019

Note that the core detection bandwidth is usually less than the full bandwidth of all vocalizations within a given species' repertoire since the full frequency range is not always needed to successfully detect every species.

shorter recording periods may improve accuracy of daily acoustic presence. Duty-cycling effects are most pronounced for species with low and/or temporally clustered calling activity (Thomisch et al., 2015)—i.e., non-song call types such as the North Atlantic right whale—and are less pronounced for species that click over long time intervals, such as beaked whales (Stanistreet et al., 2016). For higher frequency species, a PAM click detector recorder can be an efficient method for data collection (e.g.,

TABLE 2 | A list of the primary odontocete species found along the Atlantic Outer Continental Shelf and their primary call type, frequency range, and core detection bandwidth.

Species/Groups (North Atlantic)	Main Call Types (primary behavioral function)	Min Frequency (kHz)	Max Frequency (kHz)	Core Detection Bandwidth (kHz)	References
Sperm whale	Clicks (foraging and social)	0.1	35	5–25	Madsen et al., 2002
Pygmy and Dwarf sperm whale	Clicks (foraging and social)	100	135	115–135	Merkens et al., 2018
Delphinids (Bottlenose, Spotted, Atlantic White-Sided, and Common Dolphins)	Clicks (primarily foraging)	30	140	40–130	Au et al., 1982, Au and Herzing, 2003
	Whistles (social)	3.5	23.5	8–15	Ansmann et al., 2007, Baron et al., 2008, May-Collado and Wartzok, 2008
Pilot whale	Clicks (primarily foraging)	2	120	12–30	Eskesen et al., 2011, Baumann-Pickering et al., 2015
	Whistles and Pulsed Calls (social)	0.8	16	3.5–6	Weilgart and Whitehead, 1990, Baron et al., 2008, Nemiroff and Whitehead, 2009
Northern bottlenose whale	Clicks (foraging and social)	15	45	20–35	Clarke et al., 2019
Cuvier's beaked whale	Clicks (foraging and social)	15	50	30–45	Baumann-Pickering et al., 2013
Blainville's beaked whale	Clicks (foraging and social)	20	60	25–45	Baumann-Pickering et al., 2013
Gervais' beaked whale	Clicks (foraging and social)	25	100	30–70	Baumann-Pickering et al., 2013
True's beaked whale	Clicks (foraging and social)	30	100	40–60	DeAngelis et al., 2018
Sowerby's beaked whale	Clicks (foraging and social)	50	90	55–80	Clarke et al., 2019
Harbor porpoise	Clicks (foraging and social)	100	150	115–140	Au et al., 1999

Note that the core detection bandwidth is usually less than the full bandwidth of all vocalizations within a given species' repertoire since the full frequency range is not always needed to successfully detect every species.

Bailey et al., 2010a; Temple et al., 2016; Wingfield et al., 2017). The click detector recorder stores continuous higher frequency clicks of delphinids, harbor porpoise, and other high-frequency odontocetes but does not provide a PAM sound record as is the case for most other recorders.

Archival PAM systems are often moored near the seabed with no surface expression and are returned to the surface by divers or by using an acoustic release mechanism. Acoustic data are therefore only recovered and analyzed at the end of the recorder deployment. Consequently, the analyses that are conducted will be retrospective and not real time. However, the need to wait for data records until retrieval can be resolved by using archival PAM systems with surface expression such as those used by Brandt et al. (2018) allow for more frequent data collection. Archival data can be useful to build long-term monitoring records of the presence of sound producing species, both temporally (seasonal and yearly occurrence) as well as spatially (occurrence in and across different regions). These data can also be valuable for evaluating potential effects of construction as changes in species presence and behavior can be correlated with construction activities.

Real-Time PAM Systems

Real-time PAM systems that enable rapid detection and recognition of marine mammal calls are invaluable for monitoring but are essential components for mitigating potential effects from wind energy development. Real-time acoustic alerts can be used to respond quickly to the presence of protected species in a construction area (e.g., during impact pile driving as long as the presence of multiple construction noise sources do not mask their presence) or in the vicinity of transiting vessels, thereby reducing the risk of vessel strike (e.g., Spaulding et al., 2009; Baumgartner et al., 2019, 2020, 2021; Norris et al., 2019; Kowarski et al., 2020; Wood et al., 2020). Real time is defined here as the relay of PAM data (processed or raw) within an operationally usable time span (e.g., data relay frequency may range from every minute, hour, to daily, depending on how quickly the information is needed for decision-making). In effect, any data from the acoustic detection can be used to optimize, or at least provide, timely information to help direct current operations and/or tracking of a species (Klinck et al., 2012; Baumgartner et al., 2013, 2019, 2020; Kowarski et al., 2020). Real-time PAM can also be used to improve and adjust to noise produced by pile driving, by offering real time feedback on the noise produced by the hammer and the capacity to adjust this if needed. Real-time PAM can be conducted from a variety of platforms, including vessels, surface buoys, autonomous vehicles such as gliders, and drifting buoys. The PAM data will travel from a PAM recording sensor to the receiving station on shore/vessel at regular time intervals agreed upon in the PAM Plan. The frequency of data relay is constrained by the type and cost of data upload. Cell phone towers can be used for data relay if sensors are located close to land, as reception tends to be lost beyond 15 miles offshore. Iridium satellite data transmission (currently the most common type) costs are based on the quantity of data and frequency at which you want to upload, and which data service plan you select. Another possible option is cabled arrays laid out on the seafloor, which can also provide a real-time data feed straight to shore where such an installation is feasible [e.g., Lindsey et al. (2019)].

PAM Recording Technologies

There was an ever-increasing number of PAM technologies, varying in recording and data collection capabilities, available to broader science, management, and industry communities (**Figure 1**). The following represent several of the general categories of recording technologies currently available. The considerations and recommendations provided in the PAM System Types section ("PAM System Types") above should be evaluated based on the chosen recording technology.

PAM Fixed, Bottom-Mounted Archival

Passive acoustic monitoring fixed, bottom-mounted archival recorders are moored on or near the ocean floor for several weeks to months (many recorders can now record continuously for 4 to 6 months), and up to several years. They should be spaced at distances that encompass the estimated calling/detection radius of the species of interest when they are within, and in the vicinity of, the operating area. The detection radius will vary depending on a number of factors, including those influencing signal propagation (i.e., water depth and temperature, substrate type, noise levels), as well as source level and directivity differences in calls between individuals and species. An estimate of the minimum number of hydrophones needed for detection of the call types of the species of interest should be made and hydrophones placed with these considerations in mind to minimize potential missed portions of the operating or surrounding areas (**Figure 4**; **Table 3**). The percentage of area that is desirable or required to be covered by the hydrophone spacing needs to be considered. An example of such a design can be seen in **Supplemental Information I**, where we aim to have 100% coverage of the acoustic radius of a calling North Atlantic right whale individual within the lease block areas and 50% coverage outside of the areas. In addition, where required, multi-element bottom-mounted hydrophone arrays can be used to track the movements of calling individuals (e.g., Stanistreet et al., 2013).

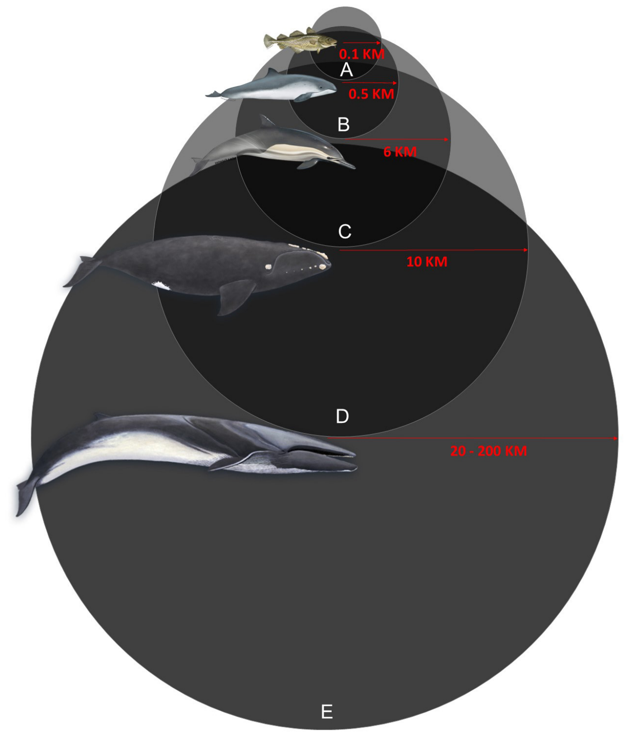

FIGURE 4 | This figure provides a stylized example of the average acoustic detection ranges of varying categories (A–E) over which different species groups and representative call types for each can be heard. Detection range A covers 0.1 km and includes sounds such as Atlantic cod (*Gadus morhua*) grunts. Detection range B covers up to 0.5 km and includes harbor porpoise (*Phocoena phocoena*) clicks and other fishes. Detection range C covers up to 6 km and generally includes dolphin species whistles. Detection range D covers up to 10 km and includes vocalizations of baleen whale species such as North Atlantic right whale (*Eubalaena glacialis*) upcalls and sperm whale (*Physeter macrocephalus*) clicks. Detection range E covers a range from 20–200 km and represents vocalizations of other baleen whale species such as blue whale (*Balaenoptera musculus*) and fin whale (*Balaenoptera physalus*) song. Circles sizes are not to scale.

PAM Fixed Surface Buoys, Real Time and Archival

Passive acoustic monitoring surface buoys are a valuable technology used for both relaying real-time information at regular intervals as well as collecting long-term archival data from a single location. They have been used effectively for monitoring and for mitigation purposes, spaced at appropriate listening distances for the species of interest, in busy shipping lanes, as well as in numerous other areas, including prospective wind leases (**Table 3**; **Supplementary Information II**). As there is a connection to the surface, noise produced by the mooring/floatation system can add unwanted noise and must be carefully considered in the design phase. In the cases where these buoys have been used successfully, the surface recorders were anchored using a special mooring system constructed to reduce noise (e.g., Baumgartner et al., 2019). PAM moored surface buoys are essential for the purpose of real-time mitigation, but they are also extensively used for long-term monitoring of species presence. PAM real-time buoy systems should be placed with similar listening distances in mind as for PAM bottom-mounted recorders. However, depending on the use of the platform and requirements, the number of moored surface buoys may differ. If the intent is to minimize ship strikes in a high vessel transit area, the PAM moored surface buoys should cover the vessel transit lanes (see example in **Table 3** and **Supplementary Information II**). However, if the intent is to listen for the presence of endangered species in the vicinity and within the wind lease construction area, then the number and spacing of buoys should reflect the effective listening area

TABLE 3 | A list of the PAM platform types that are currently used for the collection of data for monitoring or mitigation purposes, the spatial scale over which they can collect data, the format and type of data collected, and the current applications in which they have been used to date.

Platforms	Spatial Scale	Data Format	Data Type	Data Application
PAM Fixed Bottom Mounted	Small/Medium – limited to hearing radius around location of the mooring	Dense – continuous data collection	Archival	Baseline long-term monitoring Example: https://apps-nefsc.fisheries.noaa.gov/pacm/
PAM Fixed Surface Buoy	Small/Medium – limited to hearing radius around location of the mooring	Dense – continuous data collection	Archival and Real Time	Mitigation and baseline long-term monitoring Examples: Shipping Lanes – https://portal.nrwbuoys.org/ab/dash/\penalty-\@M Mitigation and Monitoring –http://robots4whales.whoi.edu https://apps-nefsc.fisheries.noaa.gov/pacm/
PAM Autonomous Underwater Vehicle	Large – can survey large spatial area	Sparse – Point sample data along slow moving tracklines	Archival and Real Time	Mitigation and baseline long-term monitoring Examples: http://robots4whales.whoi.edu\penalty-\@M https://www.jasco.com/oceanobserver
PAM Drifters	Large – can survey large spatial area	Sparse – Point sample data dependent on current, tide and wind	Real Time	Mitigation and baseline long-term monitoring
PAM Towed Array	Large – can survey large spatial area	Medium – Line transect sampling of areas covered	Archival and Real Time	Mitigation and baseline long-term monitoring Example: https://apps-nefsc.fisheries.noaa.gov/pacm/

that needs to be covered (see **Supplemental Information II** for an example).

PAM Autonomous Underwater Vehicles and Autonomous Surface Vehicles, Real Time and Archival

An Autonomous Underwater Vehicle is a robot that travels underwater without requiring input from an operator. Underwater gliders are a subclass of Autonomous Underwater Vehicles and can have a single PAM recorder or a PAM array placed inside or strapped to the outside of the vehicle. Autonomous Underwater Vehicles are boats or ships that operate on the surface of the water without a crew and can similarly be equipped with PAM recording equipment. PAM Autonomous Underwater Vehicles are very versatile and increasingly used to monitor large spatial areas [with the capacity to cover 10 to 1000 s of kilometers (Baumgartner et al., 2020)] over long time periods (generally from 3 to 6 months) and to relay back information either in real time or through archival recordings. They can be programmed to follow tracklines and navigate to new positions throughout a deployment, either diving up and down the water column to collect oceanographic data or following a straight path at a set depth. Gliders can be categorized into battery-operated gliders and wave-propelled gliders. The former have been demonstrated to be highly effective for real-time monitoring and mitigation for North Atlantic right whales and other baleen whale species (**Table 3**; Baumgartner et al., 2014, 2020; Kowarski et al., 2020). They have also been shown to be valuable in understanding the spatial distribution of toothed whales, such as beaked whales (Klinck et al., 2012). Wave gliders have had some success in archival monitoring of toothed whales (Küsel et al., 2017) but still require further development. In particular, the self-noise produced by the wave glider continues to limit the detection capability of low-frequency baleen whales (Baumgartner et al., 2021). Further technological development may be able to shield this noise in the future. Similarly, Autonomous Underwater Vehicle technologies, such as sail drones and self-navigating vessels, are in development and will likely present new and innovative solutions to add to the current suite of real-time and archival solutions for PAM in the near future (Klinck et al., 2009; Mordy et al., 2017).

Autonomous Underwater Vehicles are ideally suited for monitoring an area to inform BOEM and NOAA mitigation requirements. Their tracklines can be remotely piloted or redirected if needed while the instrument is out at sea. For example, if the glider locates an area of high vocal activity, it can be instructed to stay in place and only move on once the activity has decreased. Currents and wind can influence coverage of tracklines, and this needs to be taken into consideration during the design process (**Figure 5**). Again, tracklines should be designed with consideration of the listening radius of the focal species and the total detection radius of the mitigation and monitoring area that is required. Gliders are slow moving instruments (∼ 3 knots) that provide point sample data. If the aim is to understand a small area in great detail so as to not miss the presence of the species of interest, then dense tracklines that are surveyed frequently are recommended. If the intention is to cover a large area to detect individuals before an activity requiring mitigation occurs or to inform BOEM and NOAA mitigation decisions over larger areas, then broader tracklines are needed to be able to cover the detection area in question. This will result in less frequent coverage of a trackline, unless several gliders are used. The detection radius and duration it would take a glider to cover the entire desired mitigation area would need to be considered in determining the confidence in monitoring of the detection area for broadly spaced tracklines over a set time period, for example over 24-hour segments. In contrast to fixed

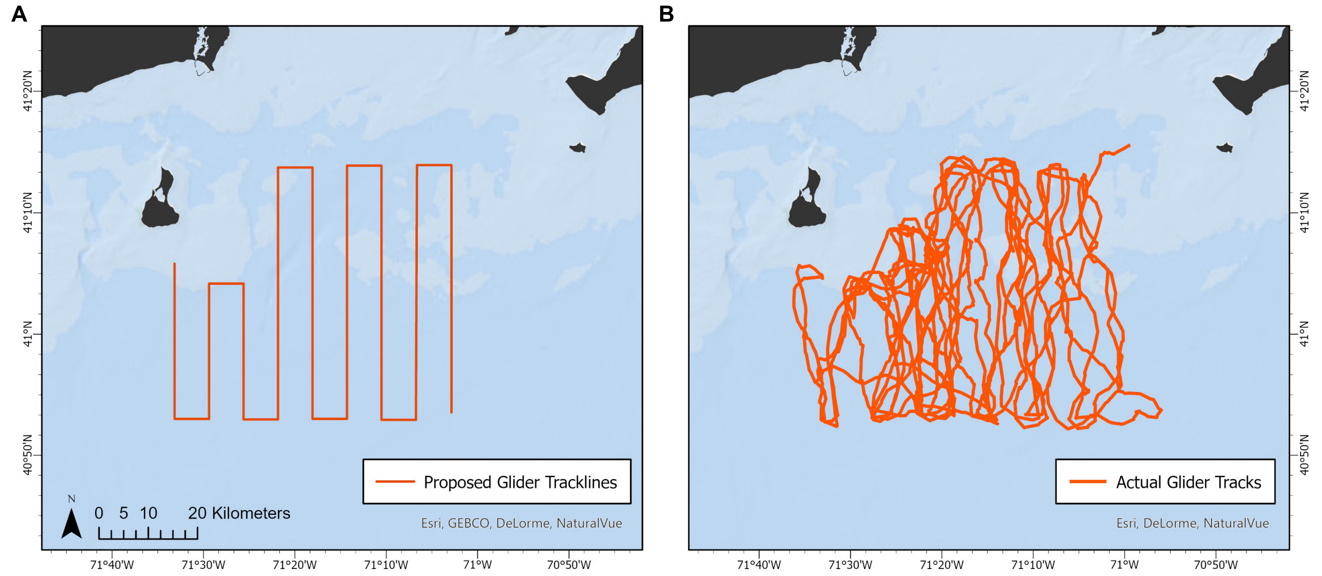

FIGURE 5 | Example of **(A)** proposed glider tracklines compared to **(B)** actual tracklines traveled from a real-time slocum glider deployment off Cox's Ledge in 2019. This design was used both for detecting spawning Atlantic cod as well as North Atlantic right whales and other baleen whale species.

recorders, the information that gliders can provide is sparse but spatially broad (**Table 3**).

PAM Drifters, Real Time and Archival

Passive acoustic monitoring drifters involve the deployment of acoustic recorders that have a single hydrophone and/or a vertical array suspended in the water column, depending on their design. They typically have a surface expression that allows for satellite tracking capabilities for subsequent recovery. Due to their surface expression, they can provide either real-time information or archival recordings, depending on what is needed. Their location and movement patterns are dependent on currents and wind. Unlike gliders, they cannot be repositioned or redirected remotely. This technology has potential, but has not yet been extensively used or tested in many studies, although it shows promise for certain applications such as monitoring species presence, estimating abundance and measuring ocean noise metrics (e.g., Barlow et al., 2014; Griffiths and Barlow, 2016; Fregosi et al., 2018). When incorporating vertical line arrays in PAM drifters, it can provide information on vertical bearing angles, thus obtaining the estimates on the depth of vocalizing animals (e.g., Griffiths and Barlow, 2016).

Passive acoustic monitoring drifter placement and density can vary greatly depending on the monitoring goal and the local oceanic conditions. Currents and wind direction would need to be well understood because they will affect each drifter independently. It is important to determine how the oceanographic conditions of the area will affect coverage of the monitoring region using these types of platforms. For example, if the site is near areas of high current, such as the Gulf Stream, the recorders may be quickly displaced when they reach that current. However, in a more sheltered, less dynamic environment, PAM drifters could provide good coverage. Drifters can be outfitted with satellite transmitters and so can be retrieved once their data collection period is over. In contrast to fixed recorders, the information that drifters can provide is sparse but spatially broad; however, unlike Autonomous Underwater Vehicles, they are constrained in the areas they cover by ocean currents, tides, and wind (**Table 3**).

Towed PAM Arrays, Real Time and Archival

When it is necessary to know the range, bearing, location, or depth of a vocalizing marine mammal (e.g., for real-time tracking or estimating abundance of individuals), an array of time-synchronized hydrophones is required (Thode, 2004; von Benda-Beckmann et al., 2010; Gillespie et al., 2013; DeAngelis et al., 2017). PAM arrays may be towed behind a vessel that is underway, but in this case, flow noise can obstruct low-frequency sounds from being heard. Generally, lower speeds produce lower flow noise; however, speed must also be considered to maintain horizontal orientation of the towed array. This generally prevents towed arrays from being useful to monitor for low-frequency baleen whale species unless the ability to record low-frequency sounds over the noise is clearly demonstrated. The Acoustical Society of America (ASA) is currently working to develop an American National Standards Institute-approved standard for towed hydrophone arrays. The fundamental goal of this ASA standard is to reduce situations where background noise levels prevent effective PAM. To achieve this goal, the standard employs a suite of strategies to standardize how acoustic measurements are logged, reported, and evaluated (Thode and Guan, 2019). Typical PAM arrays for monitoring purposes can be towed behind a vessel (or Autonomous Underwater Vehicle), in which case the tracklines to be covered by the vessel (or Autonomous Underwater Vehicle) with the array need to be designed with the listening radius of the system and species in mind (**Table 3**). Other types of arrays, such as bottom-mounted cabled arrays, are not discussed here because they are less frequently used, given the cost and infrastructure needed to lay and maintain them.

PAM Study Design

The study design is a critical component to any monitoring program and needs to be carefully defined. Both the study objectives and the capacity to address these objectives need careful consideration. Three basic questions need to be asked and addressed in any study design: Why monitor? What needs to be monitored? How should monitoring be carried out? (Yoccoz et al., 2001). PAM technology can be used to satisfy a wide range of monitoring and mitigation requirements (e.g., Bailey et al., 2010b; Forney et al., 2017; Brandt et al., 2018). In relation to wind energy development, there are several questions that most monitoring and mitigation programs need to address: does wind energy activity within and across multiple lease areas affect marine animal distribution, behavior, and communication space, and how can we reduce vessel strike risk and prevent exposure of marine animals to loud sounds during construction activities in the wind energy lease areas?

To answer the first question, baseline acoustic data collection is essential in order to build an understanding of the inter- and intra- year variability of species presence in an area. Robust baseline monitoring allows for inference to be drawn as to the cause of any observed changes and whether they are a result of oceanographic, ecological, or climatological factors, or due to anthropogenic effects. Both large-scale and small-scale trends and changes in species distribution, occurrence, calling behavior (e.g., foraging, socializing, reproduction), and movements can be derived from archival PAM data collection. For examples of large-scale monitoring studies for baleen whales see Davis et al. (2017, 2020), toothed whales see Barlow and Taylor (2005), Verfuß et al. (2007), Stanistreet et al. (2017), Carlén et al. (2018), Stanistreet et al. (2018), and fishes see Wall et al. (2012), Wall et al. (2013). For small-scale regional or area specific monitoring studies for baleen whales see Parks et al. (2007), Morano et al. (2012a), and Charif et al. (2019); toothed whales see Lewis et al. (2007), Johnston et al. (2008), and Bailey and Thompson (2010), and fishes see Rowell et al. (2015), Zemeckis et al. (2019) and Caiger et al. (2020).

Passive acoustic monitoring archival recordings are also increasingly being used to monitor the long-term ambient noise and communication space available to marine animals is a given area, in addition to the composition and health of marine soundscapes e.g., the prevalence of non-biological or anthropogenic sound sources (Clark et al., 2009; Hatch et al., 2012; Staaterman et al., 2014; Erbe et al., 2016; Merchant et al., 2016; Haver et al., 2018). Potential effects of anthropogenic activities on marine species can be evaluated through applying the collected data to analytical frameworks, such as Before-After-Control-Impact (BACI) and Beyond-BACI designs (e.g., Underwood, 1992, 1994), or Before-After-Gradient (BAG) analyses (Ellis and Schneider, 1997; Brandt et al., 2011; Methratta, 2020). Some of the first applications of BACI to offshore wind development evaluation for marine mammals are Carstensen et al. (2006) and Scheidat et al. (2011).

To answer the mitigation question on reducing vessel strikes and preventing exposure to loud construction sounds, robust real-time monitoring needs to be established throughout the impacted area and the area directly in the vicinity. The timing of data reporting and the subsequent actions taken need to clearly show how it will be effective at minimizing risk. In **Supplemental Information I** we outline and map a regional PAM monitoring design approach for long term monitoring focused primarily on baleen whales. In **Supplemental II**, we discuss design approaches and considerations for mitigation of vessel strike risk, while in **Supplemental III** we provide ISO data templates which serve as guidelines for consistent and standardized data collection.

Purpose of PAM Design

When PAM is utilized, the design intent may be to:

(1) Understand distribution of species.
This involves monitoring a given area prior to, during, and after the construction period in order to understand the presence and distribution of species of interest. The duration of this monitoring can vary, but in order to capture variation in movement patterns, data collection is recommended at least 3 to 5 years prior to construction, during construction, and at least 3 to 5 years during wind farm operation. It would be a best practice to continuously collect the data during these time periods was continuous through the three phases (pre-construction, construction, and operations). Multiple years of data from the same area are needed in order to understand the inter-annual variability in species movement. These data provide an understanding of the annual presence, occupancy, and distribution of a species; help discern the potential impact of other factors, such as climate change, that may influence distribution; and help determine the likelihood of the species being in the area during construction and/or during subsequent long-term operation. They can also help understand any changes, or lack thereof, in species' acoustic presence related to construction activities or turbine operation (e.g., Carstensen et al., 2006; Brandt et al., 2011; Scheidat et al., 2011; Dähne et al., 2013, 2017). For example, Brandt et al. (2011) were able to demonstrate a decreasing effect of construction noise on harbor porpoise acoustic activity with distance using a BAG design. Seasonal and annual variations in presence and distribution can also be analyzed with respect to oceanographic conditions (e.g., DNV KEMA Renewables Inc, 2018). Paired with metocean monitoring and visual survey data, these efforts can add meaning as both methodologies can complement each other and reduce their biases (e.g., when a marine mammal is not calling or not visible at the surface). **Supplemental Information I** provides an example of a proposed United States East Coast PAM design for understanding distributional changes of species with regards to offshore wind development.

(2) Monitoring to reduce effects on species during construction.
This focuses on monitoring a given area during the construction period of a wind development area to inform mitigation actions, such as delaying, ceasing, or proceeding with pile driving when a protected species is confirmed acoustically within a relevant impact zone (i.e., Shutdown or Clearance Zone). Rules for defining which acoustic information triggers this decision should be established in advance and in concert with visual monitoring. Applying any mitigating action based on PAM needs to be clearly thought through with consideration to limitations of each type of system and thoroughly described in the PAM Plan. **Supplemental Information II** provides an example of a proposed United States East Coast PAM design for monitoring in order to reduce effects on species during construction.

(3) Monitoring for reducing risk of vessel strike.
In order to monitor for species presence to reduce vessel strike risk, the design of the PAM system must be able to reliably detect the presence of the species of interest. Additionally, a thorough decision-making and communication process when a detection is made is needed to ensure that vessels are alerted and slow down to reduce vessel strike risk. An example of this decision-making process is the triggering of NOAA's Slow Zones[2]. These Slow Zones are established when North Atlantic right whales are detected both visually (i.e., Dynamic Management Area) and acoustically (i.e., Acoustic Slow Zone). A Dynamic Management Area is triggered when 3 or more North Atlantic right whales are sighted within 3–5 miles of one another. This criteria emerged from Clapham and Pace (2001), which showed an aggregation of three or more whales is likely to remain in the area for several days, in contrast to an aggregation of fewer whales. Given that visual and acoustic data differ, where the number of individual North Atlantic right whales cannot yet be derived from acoustic data alone, an Acoustic Slow Zone is established when three or more upcall detections from an acoustic system occur within an evaluation period (e.g., 15 min), an acoustic equivalent determined by NOAA NEFSC acoustic experts. To trigger an Acoustic Slow Zone, an acoustic system must meet the following criteria: (1) evaluation of the system has been published in the peer-reviewed literature, (2) false detection rate is 10% or lower over daily time scales, and (3) missed detection rate is 50% or lower over daily time scales. Once triggered, Slow Zones are set up as a rectangular area encompassing a circle of 15 (for Dynamic Management Areas) or 20 (for Acoustic Slow Zones) nautical miles around the core sightings (Dynamic Management Area) or recorder location at the time of detection (Acoustic Slow Zone). The Slow Zone lasts for 15 days and can be extended with additional sightings or acoustic detections. **Supplemental Information II** provides a more detailed example of a United States East Coast PAM design for reducing vessel strike risk.

All real-time PAM designs need a clear and well thought out and consistent process, including PAM placement and technology type, species detection, integration with other visual data observations, communication of information to Protected Species Operators (PSOs)/shoreside operators, and response of the information/detection. Limitations of each real-time PAM system should be well understood and considered in detail in any PAM Plan. Efficacy of the system used and its capacity to detect the signal/species of interest is essential to developing a successful and credible PAM Plan. Lastly, it is important to note that no one PAM system is capable of answering all needs and that frequently a mixture of PAM systems, technologies and designs are likely needed to address all monitoring and mitigation requirements.

PAM System and Data Analysis Requirements

In this section, we present some broad PAM system requirements both in terms of hardware needed and automated software for analysis of calls and ambient noise metric measurement. Standards and guidelines are increasing in availability (e.g., Robinson et al., 2014; van der Schaar et al., 2017; Ainslie et al., 2019), through projects such as ADEON (Atlantic Deep Water Sea Ecosystem Observatory Network[3]), JONAS (Joint Framework for Ocean Noise in the Atlantic Seas[4]), JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea[5]), additional existing practices on PAM such as the International Quiet Ocean Experiment can also be found through the Ocean Best Practices Repository[6].

PAM Hardware

For all PAM technologies, the hydrophones and related hardware need to be calibrated (every 3 to 5 years) and their performance systematically measured and optimized within frequency bandwidths of interest for the particular activity, species, and environment. Calibration data, and relevant settings and sensitivities should be noted for all hardware used in recording/monitoring to ensure consistency among measurements for particular hardware and software [more detail can be found in Biber et al. (2018)]. Array synchronization information (where relevant) should also be documented. This information should be permanently associated with the recordings as metadata.

All hardware should be tested and optimized for low self-noise, including the mooring system. In addition to calibration, the system should be fully tested to ensure adequate sensitivity in the area where it will be deployed and with the type of signals it would receive. Additional environmental data will need to be collected to allow for adequate system evaluation. If this

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[2] https://www.fisheries.noaa.gov/feature-story/help-endangered-whales-slow-down-slow-zones

[3] https://adeon.unh.edu/standards

[4] https://www.jonasproject.eu/

[5] https://northsearegion.eu/jomopans/output-library/

[6] https://www.oceanbestpractices.org/repository

cannot be done at the project site, the system should be fully tested in a comparable location (i.e., an area exhibiting similar depth, temperature, substrate, current, acoustic propagation, and ambient noise, with relevant sound sources).

At a minimum, the following specifications should be measured and reported on:

- Bandwidth and frequency response (i.e., 10 to 2000 kHz)
- System sensitivity (i.e., −207 dB re 1 V/μPa @ 1 kHz) and dynamic range (dB)
- System self-noise (i.e., the equivalent bandwidth noise pressure level)
- Gain (dB)
- Directional response (i.e., omnidirectional or angular dependent)
- Sample rate (kHz)
- Sample resolution (i.e., 12 Bits)
- Recording schedule (i.e., recording duration/interval).

The system needs to be designed, installed, and operated by those having expertise with the specific PAM technology, including placement in the water, attachment of cables to reduce strumming and noise, acoustic release, suitable anchorage for the conditions, software use, etc., Knowledgeable and experienced personnel should operate the units in all situations.

Ideally, the PAM technology used should have been used for the same purpose in other field efforts and have clear and detailed information available about its previous performance and reliability for PAM purposes. If this is not the case, this information needs to be gathered and provided in publicly available documentation as part of the PAM Plan.

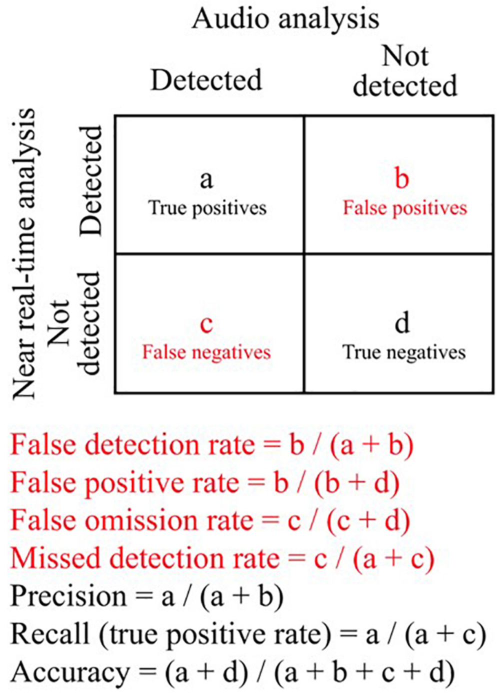

FIGURE 6 | Definitions of performance metrics for comparing occurrence estimates from the near real–time and audio analyses. A good detection process minimizes the quantities in red and maximizes the quantities in black. Replicate of Figure 4 in Baumgartner et al. (2019).

PAM Species-Specific Automated Detection Software

Passive acoustic monitoring data analyses for *species presence* should occur through either a) visual processing of data by an acoustic expert familiar with the call types of the species of interest, or b) by using comprehensively tested PAM software detector(s) for which performance has been documented, and the performance metrics are publicly available for outside evaluation and have been reviewed and deemed acceptable by a panel or group of experts. Visual review will likely be required to some degree when dealing with acoustic detection of rare species such as North Atlantic right whales and/or for ensuring data quality. Standard performance metrics require evaluation and reporting, such as precision, recall, and accuracy, as well as false detection, false positive, false omission and missed detection rates (**Figure 6**) (e.g., Baumgartner et al., 2019; Kirsebom et al., 2020; Madhusudhana et al., 2020; Gervaise et al., 2021). PAM software detectors comprise a wide range of custom-built computer programs, aimed at automating the process of detecting target species' calls in a dataset [see review in Bittle and Duncan (2013), Shiu et al. (2020), Gervaise et al. (2021)]. In both PAM archival and real-time data analysis, in addition to any software detector(s) used, some level of visual confirmation by an acoustic expert often still remains essential to improve accuracy and minimize error in call type reporting.

For *PAM archival data analysis*, where the objectives tend to focus on retrospective understanding of species presence, movements, or behavior, daily or hourly reporting of species detections are the time frames most frequently used (e.g., Davis et al., 2017, 2020; Stanistreet et al., 2017; Halliday et al., 2019). This method can speed up the process of data analysis by only requiring a positive species confirmation at the hourly or daily level. For example, when evaluating the presence of North Atlantic right whales along the United States East Coast, the presence of three upcalls within a 24-hour time period serves as the determination that at least one whale is present during that day (Davis et al., 2017). Three upcalls, rather than a single upcall, are used in order to decrease the likelihood of incorrect species determination given that other baleen whales can produce similar calls to North Atlantic right whale upcalls (Davis et al., 2017). However, each species and call type will require different levels of additional verification as needed (if any) and decisions made as to what level of certainty is acceptable. For example, automated detectors for 20 Hz fin whales have a high detection accuracy (e.g., Morano et al., 2012b), and, in this case, it may be reasonable to simply take the detector output with no further evaluation.

For *PAM real-time data analysis,* additional visual verification of the detected sound is likely to be needed since the occurrence of a given call type may influence whether operations are able to continue or are required to shut down (in the situations where shut down is possible). The ability to satisfy this confidence metric can be achieved by carrying out PAM training for operators and through evaluation of detections by analysis experts. A PAM expert is defined as a scientist who has 6 months or more of experience working with the call types of the species of interest, who can distinguish between confounding sounds (Kowarski et al., 2020), and who has experience working with the relevant detection software. Additionally, established and publicly available protocols on how a species is determined present for the specific PAM system and software must be documented in the PAM Plan.; for an example, see DeAngelis et al. (2016).

All PAM Plans should provide clear documentation of the efficacy of their detection capabilities and classification software for the specific signals of interest. Examples of comprehensive testing for real-time and archival PAM can be found in Baumgartner et al. (2019, 2020), Kowarski et al. (2020), and for PAM towed arrays can be found in Gillespie et al. (2013).

The PAM Plan should demonstrate for all PAM systems and moorings that (a) the species' signal of interest can be heard reliably beyond the self-noise, and (b) any detection and classification software that is used has (1) been tested; (2) clearly documented reliability in detecting a given species; and (3) software performance metrics that are openly available.

PAM Localization

Localizing calling species during the construction phase of offshore wind projects would be very useful for satisfying mitigation requirements regarding the location and distance of the species in question, relative to the sound source (e.g., pile driving location). Localization can be carried out by the placement of multiple fixed or mobile omnidirectional hydrophones arranged in a configuration that allows for localization of the vocalizing animal using the difference in the time of arrival of a call (or calls) on multiple time-synchronized sound recorders (e.g., Stanistreet et al., 2013; Hastie et al., 2014; Risch et al., 2014; Gillespie et al., 2020; Gervaise et al., 2021). It can also be achieved by using multiple sensors that can calculate bearing [e.g., directional autonomous seafloor acoustic recorders (DASARs); Greene et al., 2004; Blackwell et al., 2007; Mathias et al., 2012; Blackwell et al., 2013]. For stationary systems, a minimum of three hydrophones placed within a range that guarantees overlapping receptivity (i.e., multiple arrivals) is necessary to localize the positions of vocalizing animals using time-of-arrival methods (e.g., Stanistreet et al., 2013; Tremblay et al., 2019). Sensor positional, timing, and speed accuracy all need to be considered, as well as sensor configuration (geometric dilution of precision). However, for mobile platforms, such as a ship with a linear towed hydrophone array, two or more hydrophones can be used for the calculation of bearings; sequential bearing calculated as the platform moves can be used to estimate the location of calling animals (i.e., time-motion analysis, typically with left-right ambiguity) (e.g., von Benda-Beckmann et al., 2010; von Benda-Beckmann et al., 2013). In most cases, decisions on mitigation measures (e.g., pile driving shutdown when feasible or vessel speed reduction) can be made simply based on the range of calling animals from the noise source, without resolving the left-right ambiguity issues or knowing the bearing of the calling animal. However, under certain situations with anisotropic noise propagations, it would be necessary to know the location of the calling animal. Under such situations, localization and methodology should be included in the PAM Plan to approximate locations of the animal or sound source for purposes of taking action. Bottom-mounted recorders, real-time systems, towed and vertical arrays, and drifters can all be used for localization purposes, depending on the accuracy needed and the species of interest. Determining which system and technology to use requires careful consideration and supporting evidence to demonstrate that the design is appropriate. The analytical component of localization can be highly time consuming, which can be costly, and each array design requires careful documentation of the localization errors of the system.

PAM Ambient Noise Metrics

The measurement of background sound levels—i.e., *ambient noise metrics*—is an additional and important dataset that can be obtained from acoustic recordings made on any platform. Although the primary focus of this effort is to document the vocalizations of marine mammals, additional acoustic analyses of abiotic acoustic sources in the same recordings can reveal temporal patterns in distinct frequency bands that correlate with other factors such as wind speed. Ambient noise metrics could also document the level of potential increases in ambient noise due to wind farms. Metrics for the coincidental recording of ambient noise should be included in PAM Plans and include factors anticipated to be associated with offshore wind development such as vessel traffic and operational noise. These kinds of ambient noise metrics provide a record of acoustic conditions in a given environment and are essential for understanding changes in the sound levels across different regions and time (Dekeling et al., 2014). Currently, available standards and those in development can be found by searching the Ocean Best Practices Repository (see foot note 1). Measurements of ambient noise metrics can be carried out using a number of open source programs such as PAMGUIDE (Merchant et al., 2015[7]) or MANTA[8]. These programs provide a standard series of measurements at the decidecadal level that can be replicated across projects. An ongoing framework inventory on existing standards for observations of sound in the ocean can be found in the Ocean Best Practices Repository (International Quiet Ocean Experiment WG on Standardization, 2018).

PAM Archiving, Reporting, and Visualization

Here we define PAM archiving as (1) the storage of recordings in a publicly accessible location; (2) PAM reporting as the reporting of data outputs such as detections, locations, or bearing of species-specific calls in a structured and publicly available venue; and (3) PAM visualization as the representation of these data outputs on a publicly available website.

PAM Archiving

Passive acoustic monitoring archiving is essential in order to provide a long-lasting record of the efforts invested in PAM

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[7] https://sourceforge.net/projects/pamguide

[8] https://bitbucket.org/CLO-BRP/manta-wiki/wiki/Home

data collection. PAM archival and real-time datasets require the archiving of several items:

- The acoustic sound recordings, which are the raw sound recordings made using the PAM technology, should be compressed into a standardized lossless format such as FLAC for archiving.
- The associated metadata, which is the information associated with the deployment and retrieval of the PAM technology at sea (e.g., recorder type, depth, location, and functionality) and information on the recording settings, such as the sampling rate and recording schedule.
- Derived analytical products, such as the software program used and evaluation of efficacy of species detection, number of hourly or daily species detections, sound source levels, and other relevant measured sound parameters.

Archiving of acoustic sound recordings is encouraged through NOAA's National Center for Environmental Information (NCEI) archiving service[9]. PAM metadata are required criteria for archiving at NCEI. The process and metadata details can be provided upon request. These should be used as a guide in PAM Plans for documenting relevant information regarding the field recording effort (deployment and retrieval information), as well as resulting analyses (such as species detections or noise metrics).

PAM Detection/Data Reporting

All confirmed passive acoustic detections of target species/species, whether from archival or real-time data, must be archived in a publicly accessible location. For the United States East Coast, all species detection data and ambient noise metrics should be reported to the Northeast Passive Acoustic Reporting System via nmfs.pacmdata@noaa.gov. Formatted spreadsheets that follow ISO standards with required detection, measurement, and metadata information are available for submission purposes (see **Supplemental Information III** for details). When real-time PAM is used during construction for mitigation purposes, a subset of the information required on species detections is expected to be provided and uploaded no later than 24 after the detection. Full acoustic detection data, metadata, and GPS data records must be submitted within 48 h via the formatted spreadsheets. When PAM is used for long-term monitoring, all data (detection data, metadata, GPS data, and ambient noise data) should be provided via the formatted spreadsheets and uploaded within 90 days of the retrieval of the recorder or data collection. The spreadsheets can be downloaded from https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates. For further assistance, contact nmfs.pacmdata@noaa.gov.

PAM Data Visualization

All PAM detections and metadata submitted to the Northeast Passive Acoustic Reporting System are visualized on the Passive Acoustic Cetacean Map[10]. We encourage PAM detections to be shared across widely used and recognized platforms and regional web portals; for the United States East Coast, some of these standardized efforts are the Passive Acoustic Cetacean Map (see foot note 10), WhaleMap[11], and WhaleAlert[12].

CONCLUSION

These PAM recommendations provide a guide to understanding the various aspects required for designing and conducting PAM for both monitoring and mitigation. While the PAM Plans approved by agencies will ultimately determine full requirements, this six-step process provides a holistic look at each of the components that are needed when considering the development of a PAM Plan as well as long-term baseline monitoring. PAM technologies are a rapidly developing area, and new technologies and applications are likely to be available in the near future. Similarly, the data collection, analysis, and archiving of these data is ever evolving as the needs and applications grow; therefore, new developments will emerge as offshore wind development gets underway. These NOAA and BOEM recommendations will be updated and improved as new information and guidance becomes available.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.760840/full#supplementary-material

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[9] https://ngdc.noaa.gov/mgg/pad/

[10] https://apps-nefsc.fisheries.noaa.gov/pacm

[11] https://whalemap.ocean.dal.ca/

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary Information I-

Baseline Long-term Passive Acoustic Monitoring of Baleen and Sperm Whales and Offshore Wind Development

1 Summary

This section provides key considerations for a long-term regional monitoring plan focused on Outer Continental Shelf (OCS) leases which currently cover the North and Mid-Atlantic offshore wind planning areas from the Gulf of Maine to South Carolina. The primary focus of this monitoring protocol is to determine whether there are large-scale, long-term shifts in baleen whale distributions as a result of wind farm construction and operation. This system is *not* designed for real-time detection of animals during pile driving associated with wind farm construction or monitoring to reduce vessel strike risk (see Supplementary Information II for this). In doing so, we follow the six step process discussed in detail in the passive acoustic monitoring (PAM) recommendations by the National Oceanic and Atmospheric Administration (NOAA) and Bureau of Ocean Energy Management (BOEM) recommendations.

1.1 Species of Interest

The focal species of the PAM regional monitoring plan recommended for the U.S. Atlantic OCS are baleen whales, with a priority on endangered species listed under the Endangered Species Act or critically endangered on the International Union for Conservation of Nature Red List. These species are the critically endangered North Atlantic right whale (NARW), *Eubalaena glacialis*; endangered fin whale, *Balaenoptera physalus*; blue whale, *Balaenoptera musculus*; sei whale, *Balaenoptera borealis*; and sperm whale, *Physeter macrocephalus*. In addition, other baleen whale species—such as minke, *Balaenoptera acutorostrata*, and humpback, *Megaptera novaeangliae*, whales—routinely use these areas as well. In particular, the NARW is a largely coastal species spending most of its time near shore on the shelf. Its critically endangered status renders it the primary focus for potential effects of offshore wind development and other anthropogenic activities. The NARW and other species are predominantly low-frequency sound producers (except for the sperm whale) and the primary anthropogenic noise produced by construction and operations produce main energy in these low-frequency bands. Therefore, all PAM recording technologies, PAM system requirements, and PAM designs at a minimum need to be constructed with low-frequency requirements in mind (see Table 1). Consideration should also be given to the frequency requirements required to capture the core detection bandwidth for sperm whales and delphinids (see Table 2). If there is an interest in detecting other species, the addition of instruments such as C- or F-POD click detectors can be collocated with PAM recorders to collect additional information on odontocetes' click presence.

1.2 PAM Data Collection Approaches

Long-term monitoring generally requires detailed information collected in a given area in order to build a baseline time series of species-specific presence. PAM provides long continuous time series with low spatial resolution, while visual surveys provide snapshots with low temporal resolution but high spatial resolution. Continuous PAM archival recorders are best suited to this particular type of effort, since they provide an uninterrupted (24hours/7 days) record of species presence and can provide robust context to observed changes. If necessary, duty cycled recordings can also be used, though are less preferred as they reduce the efficacy of species detection as discussed in the NOAA and BOEM PAM recommendations. Monitoring of this nature and subsequent analyses are best served if data are collected for a minimum of 3 to 5 years immediately prior to construction, for the duration of construction, and for a minimum of 3 to 5 years immediately after construction and during offshore wind farm operation. Replication across several years is necessary in order to understand the variability in species presence on an annual and interannual basis, and, if possible, this effort would benefit if data were collected continuously from prior to construction through operation.

1.3 PAM Recording Technologies

With regard to PAM recording technology, fixed bottom-mounted archival recorders are the tool of choice for long-term monitoring efforts as they can often be deployed for long periods of time (see Table 3). PAM technologies that provide real-time data streaming also have archival capabilities, so these can be paired for multipurpose use, i.e., for both purposes of baseline monitoring and situational awareness. Autonomous underwater vehicles that provide point sample data across a large spatial area do not create the time series records ideal for long-term monitoring, instead they are better suited for mitigation (see Supplemental II; Table 3).However, they can definitely add value by expanding data collection in areas that have a gap in PAM coverage and are otherwise not readily accessible for monitoring. PAM Study Design.

As the core species of interest, the critically endangered NARW's call type, the upcall, which serves for inter-individual communication (e.g., Clark 1982), can be heard over an average calling *radius* of 10 km across most habitats (Figure SI-1; e.g., Morano et al. 2012, Tennessen and Parks 2016, Johnson et al. et al. 2020, submitted). Based on this calling radius, spacing fixed, bottom-mounted archival recorders at intervals of 20 x 20 km would minimize the chance of NARWs not being heard when acoustically active in an area and would provide as close to 100% coverage as possible (Figure SI-1). All other primary species of interest can be heard over greater distances (see Table 2; e.g., Davis et al. 2020) and would be acoustically captured at this spacing. However, we highly recommend that a method for testing detection range (e.g., Gervaise et al. 2021, Johnson et al. submitted) is incorporated into the PAM design, even at a coarse scale, thereby ensuring that the acoustic properties and noise characteristics of specific sites conform to this recommendation. This evaluation is particularly important for shallow or highly noisy areas (e.g., shipping lanes) as they may reduce the calling radius and require a denser series of PAM recorders to ensure full coverage.

With this information in mind, we propose a design for PAM Regional long-term Monitoring Plan **WERPAM** (Wind Energy Regional Passive Acoustic Monitoring) in North and Mid-Atlantic offshore lease areas and wind energy areas (Figure SI-2). The coordinates and related grid cell information can be obtained at Northeast Ocean Data Portal and Mid-Atlantic Ocean Data Portal at NROC: https://www.northeastoceandata.org/RrTAeObF and MARCO: https://bit.ly/3B8pXn5. The direct data download link is the same for both: https://www.northeastoceandata.org/files/metadata/Themes/ProposedPassiveAcousticNetwork.zip. With such a broad spatial and temporal deployment of PAM resources, coordination across wind developers, State and Federal agencies, and associated groups is critical for the successful implementation, operation, dissemination, and utility of this regional monitoring approach.

WERPAM is based on achieving 100% acoustic coverage of NARWs by using 20 x 20 km grid cells spacing throughout offshore wind energy lease areas and larger 40 x 40 km grid cells aimed at connecting the offshore wind energy areas, with suggested PAM stations centered in each respective grid cell. The latter would achieve acoustic coverage of around 50% of the area monitored, balancing the costs and logistics of collecting regional data with the ability to detect species presence across contiguous areas of interest within and between offshore wind areas. More detailed regional PAM monitoring designs can be seen for the five main wind energy areas of interest, some with current lease areas; these are the Gulf of Maine area (Figure SI-3a), Massachusetts/Rhode Island area (Figure SI-3b), New York Bight/Mid-Atlantic area (Figure SI-3c), Virginia/northern North Carolina area (Figure SI-3d), and southern North Carolina/South Carolina area (Figure SI-3e). Baseline monitoring over the larger region is essential in order to be able to understand changes in species presence at a relevant scale for these highly migratory baleen whale species. This PAM design will allow for potential changes and effects on marine species to be evaluated through applying the collected data to analytical frameworks such as Before-After-Control-Impact (BACI) and Beyond-BACI designs (e.g., Underwood 1992, 1994), or Before-After-Gradient (BAG) analyses (Ellis and Schneider 1997, Brandt et al. 2011, Methratta 2020). The area grids will be updated as new wind energy areas are leased.

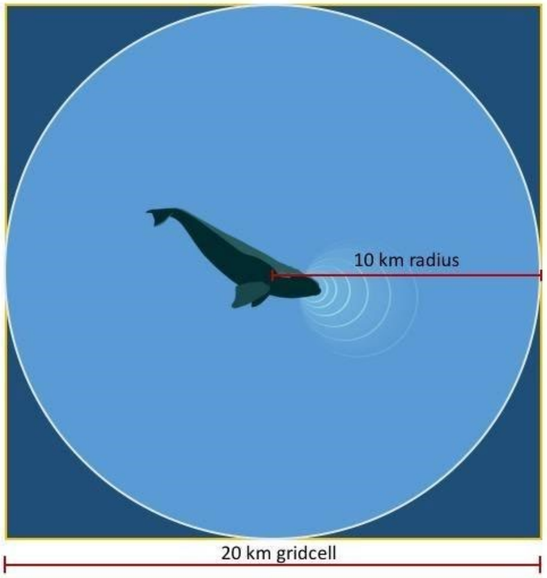
1.4 PAM System and Data Analysis Requirements

For all PAM deployments that are a part of this long-term regional monitoring approach, all hardware specifications need to as a minimum follow those outlined in the body of the manuscript (NOAA-BOEM PAM recommendations). There are a large number of automated software programs that have been designed for PAM data analyses for extracting NARW and other large whale species presence (e.g., Gillespie 2004, Urazghildiiev and Clark 2006, 2007, Gillespie et al. 2009, Urazghildiiev et al. 2009, Dugan et al. 2010, Baumgartner and Mussoline 2011, Esfahanian et al. 2017, Shiu et al. 2020, Gervaise et al. 2021, Padovese et al. 2021). Even though automated software is used to speed up the process, for several species an element of visual processing for assessing the accuracy of detections is still required since species detections can be confused; e.g., humpback whales frequently produce calls that are similar to other baleen whale species in particular right whales (see Davis et al. (2017). Species detection for large whale calls can be detected call by call or each minute, hour, or day. The finer the resolution, the more fine-scale information is available for the analyses. However daily characterization of the data should be a minimum level of information provided, with hourly being a preferred reporting standard. In addition, PAM ambient noise metric analyses provide crucial information on the background noise levels in a given area and how they may affect the communication space (Clark et al. 2009, Cholewiak et al. 2018) of a given species. Standard open source software programs are available to provide approved and standardized output metrics (see NOAA and BOEM PAM recommendations for software: section 2.5.2).

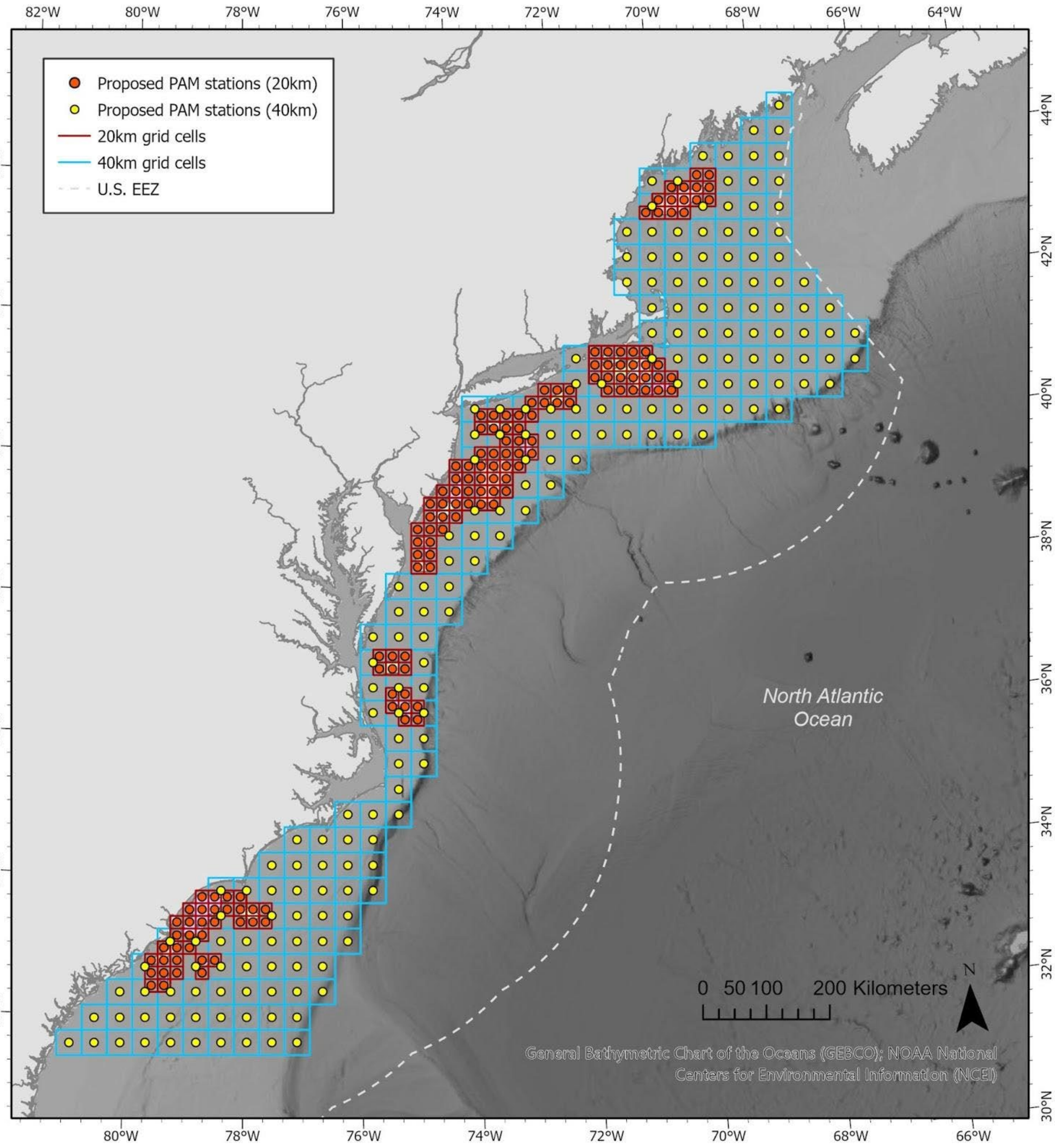
1.5 PAM Archiving, Reporting and Visualization

All archiving, data reporting, and visualization are described in the body of the manuscript. All confirmed passive acoustic detections of target species/species, whether from archival or real-time data, must be archived in a publicly accessible location. For the U.S. East Coast, all species detections and ambient noise metrics should be reported to the Northeast Passive Acoustic Reporting System via nmfs.pacmdata@noaa.gov. Formatted metadata spreadsheets that follow ISO (International Organization for Standardization) standards are available in Supplement III and online via https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates.

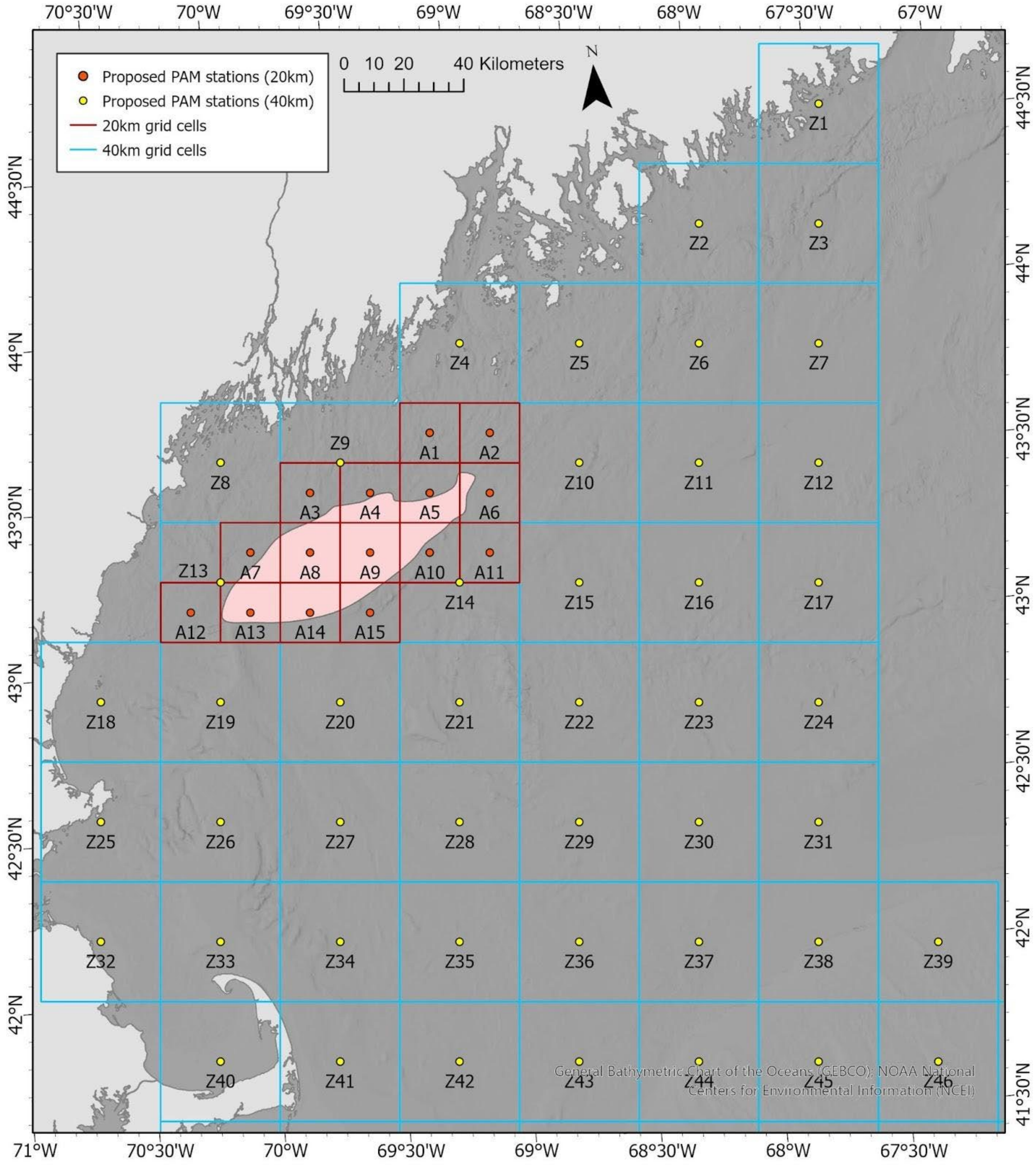
2 Supplementary Figures



Supplementary Figure SI-1: This diagram depicts the average listening radius over which a NARW upcall can be heard. It also depicts the 20-m grid cell (dark blue) and the 10-km listening radius (light blue) created around the vocalizing NARW for the purpose of designing PAM monitoring within a given area. This is the recommended listening radius; however, each PAM plan should build in a methodology for evaluating the detection range across their specific area, because bathymetry, depth, ocean temperature amongst other variables can influence how far a target sound can be heard.

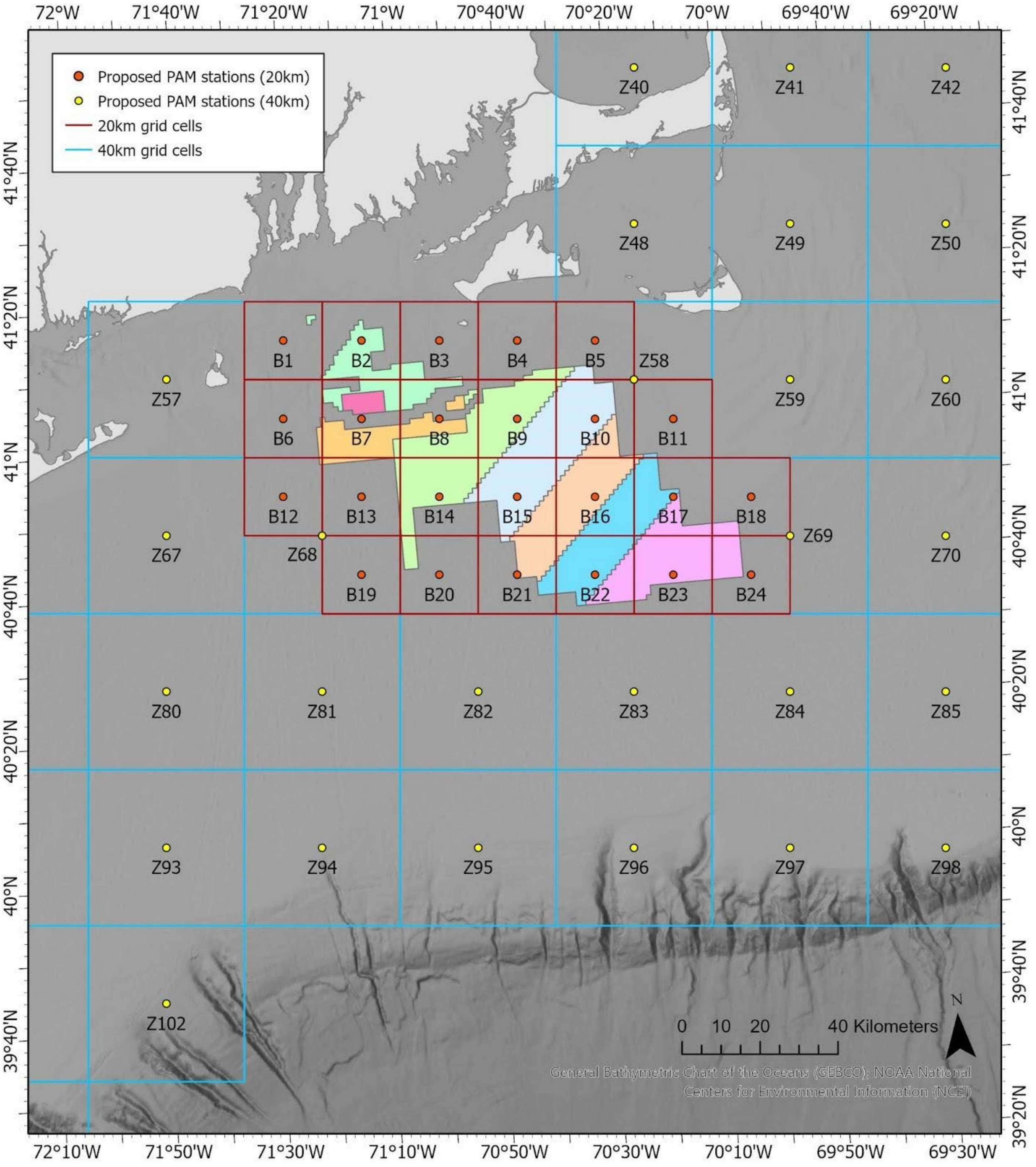


Supplementary Figure SI-2: This map provides a recommended regional WERPAM monitoring design for the Northeast U.S. offshore wind energy development areas. The red grid cells provide 20 x 20-km grid cells (red) around the development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. Bottom-type and other potential obstructions need to be evaluated before deploying on the recommended locations, and, if needed, the PAM station location can be moved to a more suitable spot within the grid cell. The coordinates and related grid cell information can be obtained at Northeast Ocean Data Portal and Mid-Atlantic Ocean Data Portal at NROC: https://www.northeastoceandata.org/RrTAeObF and MARCO: https://bit.ly/3B8pXn5. The direct data download link is the same for both: https://www.northeastoceandata.org/files/metadata/Themes/ProposedPassiveAcousticNetwork.zip. With such a broad spatial and temporal deployment of PAM resources, coordination across wind developers, State and Federal agencies, and associated groups is critical for the successful implementation, operation, dissemination, and utility of this regional monitoring approach. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.

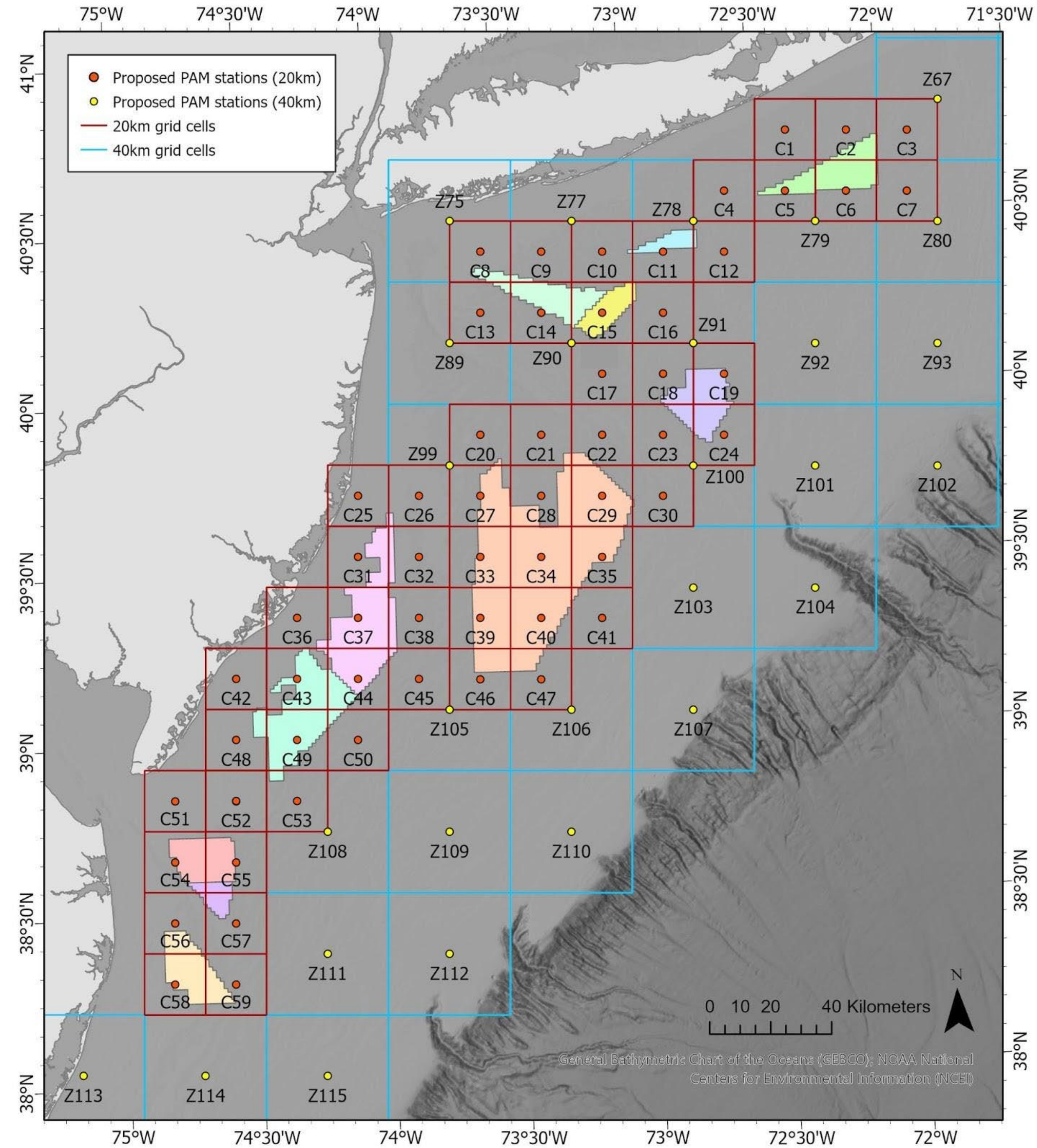


General Bathymetric Chart of the Oceans (GEBCO); NOAA National Centers for Environmental Information (NCEI)

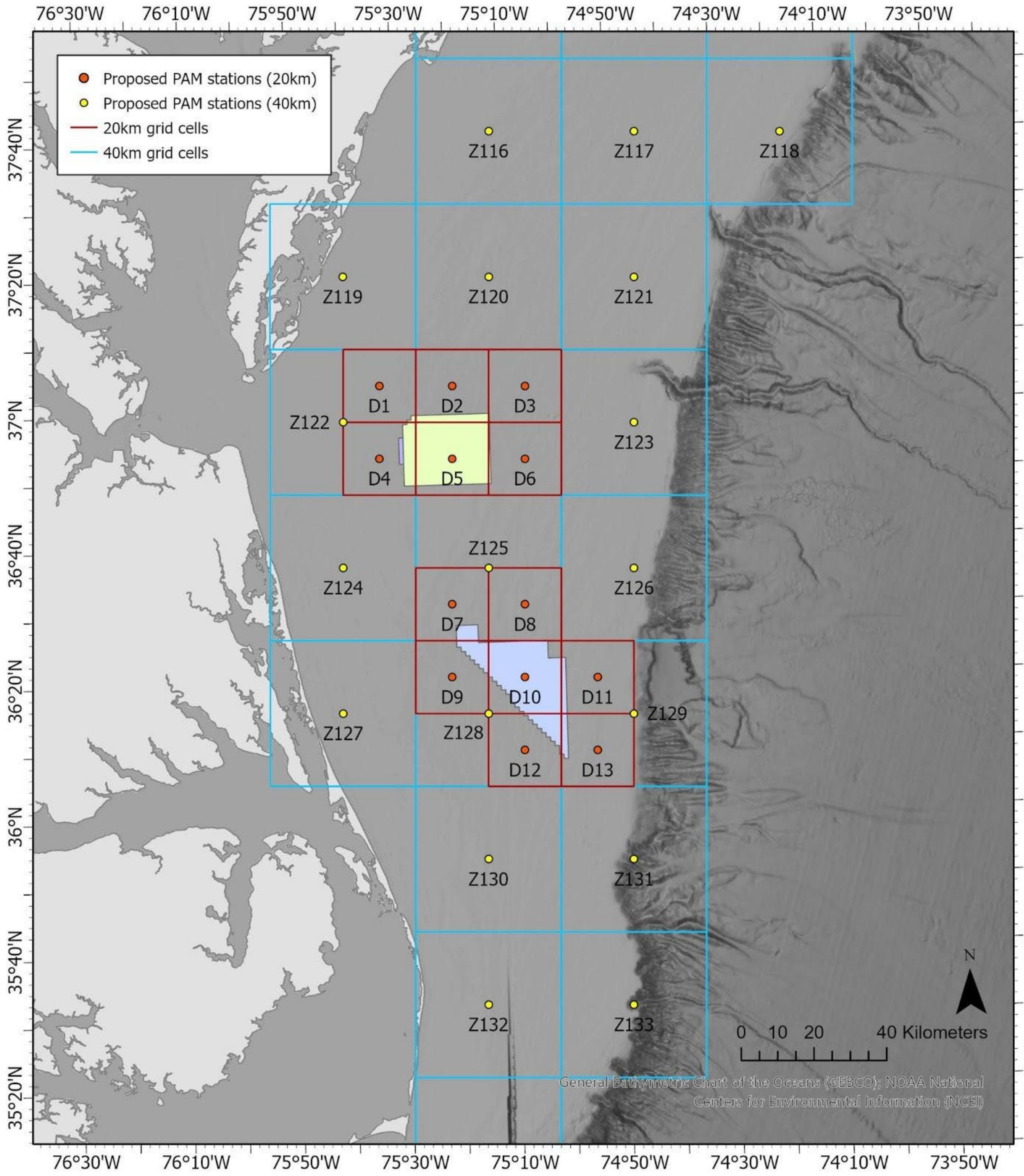
Supplementary Figure SI-3a): This map provides the WERPAM grid cells for the Gulf of Maine region. The red grid cells provide 20 x 20-km grid cells (red) around the current proposed development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.



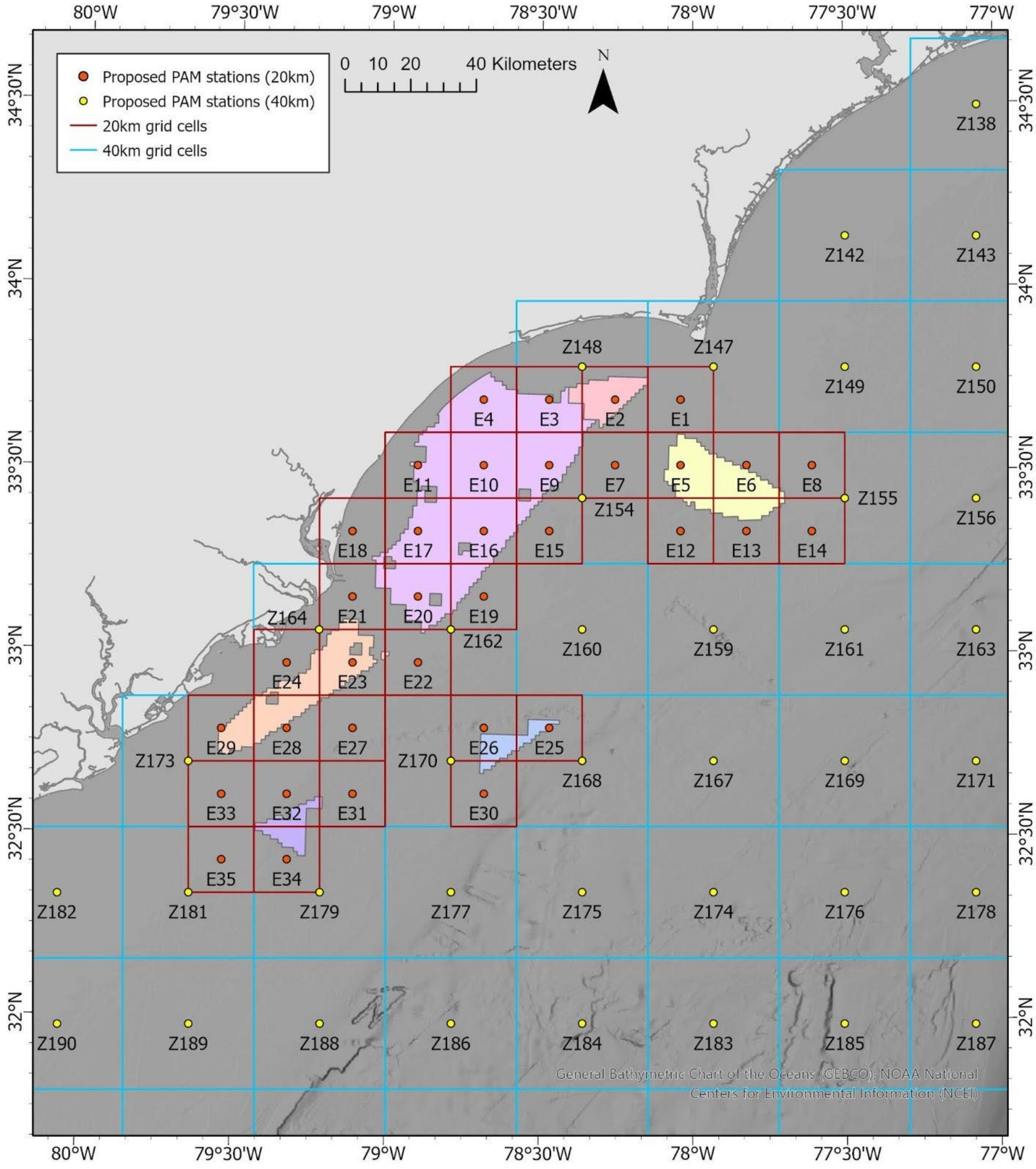
Supplementary Figure SI-3b): This map provides the WERPAM grid cells for the Massachusetts/Rhode Island region. The red grid cells provide 20 x 20-km grid cells (red) around the current proposed development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.



Supplementary Figure SI-3c): This map provides the WERPAM grid cells for the New York Bight to New Jersey region. The red grid cells provide 20 x 20-km grid cells (red) around the current proposed development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.



Supplementary Figure SI-3d: This map provides the WERPAM grid cells for the Virginia to northern North Carolina region. The red grid cells provide 20 x 20-km grid cells (red) around the current proposed development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.



Supplementary Figure SI-3e: This map provides the WERPAM grid cells for the southern North Carolina to South Carolina region. The red grid cells provide 20 x 20-km grid cells (red) around the current proposed development areas, with 40 x 40-km grid cells (blue) across the connecting areas. The proposed PAM stations (red and yellow points) denote the possible location of fixed bottom-mounted archival recorders. As the wind energy lease areas are finalized or added WERPAM locations will be updated accordingly.

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Supplementary Information II-

Passive Acoustic Monitoring During Construction and Reduction of Vessel Strike Risk for Baleen and Sperm Whales

1 Summary

This section provides an example of minimum considerations in developing a passive acoustic monitoring (PAM) Plan focused on Atlantic Outer Continental Shelf (OCS) wind lease and wind energy areas which currently cover the Gulf of Maine to South Carolina. This example is focused on two components: 1) reduction of vessel strike risk and 2) species detection during construction and operation. This example is *not* intended for large-scale, long-term regional monitoring (see Supplementary Information I for that). In this example, we follow the six step process discussed in detail in the body of the manuscript (PAM recommendations by the National Oceanic and Atmospheric Administration [NOAA] and Bureau of Ocean Energy Management [BOEM]). Of note, regulating agencies may include additional requirements for project-specific PAM Plan approvals.

1.1 Species of Interest

The species focus for the Northeast U.S. is on marine mammals classified as endangered under the Endangered Species Act or critically endangered under the International Union for Conservation of Nature Red List. These species are the following: the critically endangered North Atlantic right whale (NARW), *Eubalaena glacialis*; endangered fin whale, *Balaenoptera physalus*; blue whale, *Balaenoptera musculus*; sei whale, *Balaenoptera borealis*; and sperm whale, *Physeter macrocephalus.* In particular, the NARW is a largely coastal species spending most of its time near shore on the shelf; its critically endangered status renders it the primary focus for potential effects of offshore wind development and other anthropogenic activities. The NARW and other species are predominantly low-frequency sound producers (except for the sperm whale), and therefore all PAM recording technologies, PAM system requirements, and PAM designs at a minimum need to be constructed with low-frequency requirements in mind (see Table 1). Consideration should also be given to the frequency requirements required to capture the core detection bandwidth for sperm whales and delphinids (see Table 2).

1.2 PAM Data Collection Approaches

Real-time acoustic data collection is an essential tool that can increase situational awareness and help reduce the risk of vessel strike and the risk of acute sound exposure during construction and operation activities. Real time is defined here as the relay of PAM data (processed or raw) over a timely or operationally usable time delay. The frequency at which the data is relayed back to shore or to a nearby vessel may range from every minute, hour, or day. The selection will depend upon the speed needed to inform decision making agreed upon in the PAM Plan. Real-time acoustic information will be needed at varying degrees throughout the construction period and during operation. It is expected that other observational tools (e.g., drones, visual observers) will be used in conjunction with PAM to reduce risk to protected species.

1.3 PAM Recording Technologies

Real-time recording technologies suited to these requirements can be fixed surface buoys, autonomous underwater vehicles (AUVs), Autonomous Surface Vehicles, drifters, and possibly towed arrays. Fixed surface buoys have the capability to provide a continuous stream of real-time information when deployed in strategic locations. AUVs, such as gliders, are a mobile platform that may or may not spend some of the time sub surface and therefore may be more restricted in the timing of the real-time relays. However, AUVs are mobile and can provide track line coverage or surveillance of larger areas when needed. Both fixed surface buoys and gliders have been used previously in vessel strike reduction and risk mitigation (see examples in Section 4, PAM Design). Drifters are heavily reliant on tidal currents and wind and may have relevance where dense coverage is needed prior to or during specific construction events. Towed arrays are limited for hearing low-frequency species when a motorized vessel is underway; therefore, they are unlikely to be valuable for detecting low-frequency species unless the array is stationary.

1.4 PAM Design

The PAM design for each of these monitoring pieces will need to be considered separately since their objectives are different.

1.4.1 Vessel Strike Risk Reduction

In the case of offshore wind energy development, an array of real-time PAM systems that transect the key transit routes used during construction and maintenance activities should be established. A potential design is provided in Figure SII-1. A few real-time PAM vessel strike mitigation systems exist and are provided here as examples for possible PAM designs.

The *Transport Canada/Department of Fisheries and Oceans NARW monitoring and surveillance system* focuses on using aerial surveillance and at least six real-time PAM fixed surface buoys in addition to AUV real-time gliders, which report back 24/7 on species detected in the Gulf of St. Lawrence (https://www.dfo-mpo.gc.ca/fisheries-peches/commercial-commerciale/atl-arc/narw-bnan/narw-science-eng.html). The latest visual and acoustic detections are reported on WhaleMap (Johnson et al. 2021; https://whalemap.ocean.dal.ca/). If a NARW is visually or acoustically detected, management actions are put in place, and if a NARW is detected again during days 9–15, the action will be extended an additional 15 days. Details are available at https://www.dfo-mpo.gc.ca/fisheries-peches/commercial-commerciale/atl-arc/narw-bnan/management-gestion-eng.html.

The *Cornell University, U.S. NARW Boston Shipping Channel real-time monitoring array* (https://portal.nrwbuoys.org/ab/dash/) was designed to alert Liquid Natural Gas (LNG) tankers and other vessels to the presence of NARWs. This system uses a series of 10 real-time fixed surface buoys installed in the Boston shipping lanes (Spaulding et al. 2009). These buoys rely on an on-board automated detector to select a subset of recorded sounds that are most likely to be NARW upcalls, and a 2-second audio snippet of each of the sounds in this subset are sent to shore for aural review by an analyst. The analyst then determines whether NARWs have been detected within the 5-nautical mile range of each buoy, and if so, alert inbound LNG tankers that an NARW has been heard. When LNG ships approach the shipping lane, analysts are on duty until the ships are anchored at port, issuing updates to ships every 20 minutes. Details are also uploaded online to the Right Whale Listening Network, distributed by email, and incorporated into marine safety bulletins, including applications such as Whale Alert. With considerable advance warning, ships can be slowed or re-routed to reduce the risk of ship strike. At this time, only LNG ships are mandated to reduce their speeds in the areas around buoys that have detected whales; however, all ships are encouraged to check whale-buoy alerts and slow down below 10 knots if necessary. Slowing down increases the chance a ship's crew can spot a whale while there is still time to avoid it or give the whale a chance to move out of the way. Once a NARW has been detected, the buoy that heard the whale remains 'alight' for 24 hours (https://portal.nrwbuoys.org/ab/dash/), and LNG ships need to continue at reduced speeds. If during this time additional NARWs are detected, the 24 hour period is extended, but if no further NARWs are detected, the buoy alert is removed.

The *NOAA Slow Zone Program* These Slow Zones are established when North Atlantic right whales are detected both visually (i.e., Dynamic Management Area) and acoustically (i.e., Acoustic Slow Zone). A Dynamic Management Area is triggered when 3 or more North Atlantic right whales are sighted within 3–5 miles of one another. This criteria emerged from Clapham and Pace (2001), which showed an aggregation of three or more whales is likely to remain in the area for several days, in contrast to an aggregation of fewer whales. Given that visual and acoustic data differ, where the number of individual North Atlantic right whales cannot yet be derived from acoustic data alone, an Acoustic Slow Zone is established when three or more upcall detections from an acoustic system occur within an evaluation period (e.g., 15 minutes), an acoustic equivalent determined by NOAA NEFSC acoustic experts. To trigger an Acoustic Slow Zone, an acoustic system must meet the following criteria: (1) evaluation of the system has been published in the peer-reviewed literature, (2) false detection rate is 10% or lower over daily time scales, and (3) missed detection rate is 50% or lower over daily time scales. Once triggered, Slow Zones are set up as a rectangular area encompassing a circle of 15 (for Dynamic Management Areas) or 20 (for Acoustic Slow Zones) nautical miles around the core sightings (Dynamic Management Area) or recorder location at the time of detection (Acoustic Slow Zone). The Slow Zone lasts for 15 days and can be extended with additional sightings or acoustic detections. Figure SII provides a more detailed example focused on a regional design for reducing vessel strike risk in the Massachusetts/Rhode Island region. However, this design can be applied to all wind energy lease areas.

1.4.2 NARW Species Detection During Construction and Operation

Real time PAM recordings are the most appropriate method for avoiding noise impacts on species of interest during construction in addition to reducing vessel strike risk during construction and operation. Similar to vessel strike reduction risk, real-time PAM monitoring is essential to raising awareness and making the decision to delay or halt operations when protected species are detected. The number of real-time recorders and spacing will need to be determined on a project-by-project basis to suit the project need(s) for real-time species detection information that may be used prior to and continuously during pile-driving operations and other activities. At a minimum, the real-time recorder(s) should be located no closer than 1 km (or the closest distance to avoid masking by project noise) from the pile being driven and should be capable of and placed in locations that allow for a 10-km detection radius from the pile-driving operations. Acoustic monitoring should begin at least 60 minutes immediately prior to the initiation of pile driving, occur continuously during activity, and continue until at least 30 minutes post pile driving. The acoustic data should be monitored continuously and viewed at the frequency range appropriate to detect the target species of interest (see Tables 1 and 2). Any target species' acoustic detections and relevant information should be communicated immediately to the agreed-upon responsible parties in the PAM Plan, such as the Protected Species Observers (PSOs) or vessel captains.

Supplementary II Material

Next, we present an example of where real-time monitoring was used previously as a trigger for mitigation.

Woods Hole Oceanographic Institution/NOAA U.S. Coast Guard's maritime domain awareness real-time monitoring. In this case, the U.S. Coast Guard was interested in understanding the presence of endangered species occurrence in the area where they routinely undertake gunnery exercise training. Real-time NARW upcall detections were reported on near-real-time occurrence estimates for humpback, sei, fin, and NARWs from a single site for a year (Baumgartner et al. 2019). In practice, the analyst reviewed detection data for this study once a day, usually between 07:00 and 10:00 local time, and the resulting near-real-time occurrence estimates were displayed on the website within minutes of the analyst's review. The near-real-time occurrence estimates were also (a) distributed directly to interested users via email and text messages, eliminating the need for users to check a website (robots4whales.whoi.edu) constantly, (b) made available in Whale Alert (www.whalealert.org), a smartphone/tablet app for iOS and Android platforms, and (c) viewable in the U.S. Coast Guard's One View software to easily allow Coast Guard personnel to monitor whale presence. For the U.S Coast Guard's purpose, they would monitor the presence of NARWs several weeks prior to their gunnery exercise operations and decide whether to proceed with operations based on whether NARWs had been acoustically present days prior to their intended operations or not. In this case, the area of Coast Guard operations was small; therefore, a single fixed moored buoy reporting in real time was sufficient (Baumgartner et al 2019).

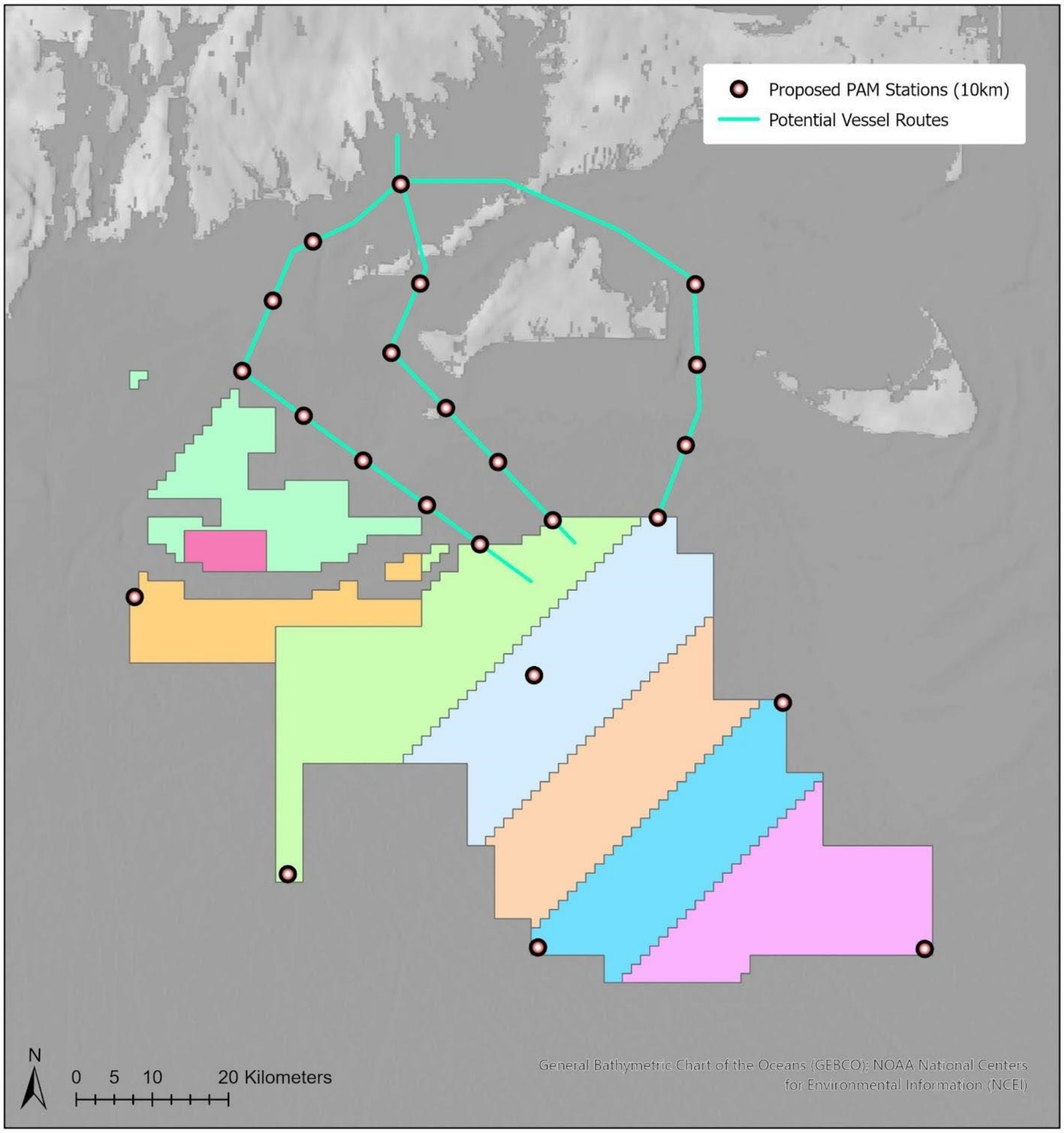
1.5 PAM System and Data Analysis Requirements

For all PAM deployments, all hardware specifications need to follow those outlined in the recommendations. A number of real-time acoustic detection software options have been developed, with several having been used extensively for detecting NARWs and other large whales (Baumgartner and Mussoline 2011, Baumgartner et al. 2019, Baumgartner et al. 2020, Gervaise et al. 2021).

1.6 PAM Archiving, Reporting and Visualization

All confirmed passive acoustic detections of target species/species, whether from archival or real-time data, must be archived in a publicly accessible location. For the U.S. East Coast, all species detection data and ambient noise metrics should be reported to the Northeast Passive Acoustic Reporting System via nmfs.pacmdata@noaa.gov. Formatted spreadsheets that follow ISO standards with required detection, measurement, and metadata information are available for submission purposes (see Supplemental Information III for details). When real-time PAM is used during construction for mitigation purposes, a subset of the information required on species detections is expected to be provided and uploaded no later than 24 after the detection. Full acoustic detection data, metadata, and GPS data records must be submitted within 48 hours via the formatted spreadsheets. When PAM is used for long-term monitoring, all data (detection data, metadata, GPS data, and ambient noise data) should be provided via the formatted spreadsheets and uploaded within 90 days of the retrieval of the recorder or data collection. The spreadsheets can be downloaded from https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates. For further assistance, contact nmfs.pacmdata@noaa.gov. The NOAA and BOEM PAM recommendations provide more detailed information on real time data analyses, design and application.

2 Supplementary Figures



Supplementary Figure SII. This map provides an example of a tentative design for PAM Fixed Surface Buoys (red dots) recording in real time, spaced at 10 km along three tentative vessel servicing channels (green lines) and at the corners of the proposed Massachusetts/Rhode Island offshore wind energy lease block area (separate lease blocks are shown as separate-colored sections).

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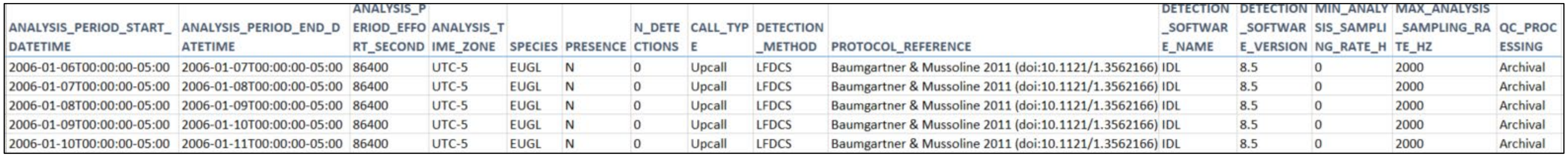
Supplementary Information III-

Detection Data, Metadata, and GPS Data Templates

1 Summary

This section provides templates for required detection submissions to the Northeast Fisheries Science Center via nmfs.pacmdata@noaa.gov. The following sheets are required for each data submission: 1) Detection data (contains all of the species' acoustic detection information and associated analyses information attached to the detections); 2) Metadata (contains all of the required metadata associated for the recorder); 3) GPS data- only for mobile platforms (i.e. gliders; contains all of the location information for recording platform tracks). Each section shows a short example of data entry, followed by field definitions. For more information and to get the most updated versions of the templates visit https://www.fisheries.noaa.gov/resource/document/passive-acoustic-reporting-system-templates. Further help can be obtained through nmfs.pacmdata@noaa.gov.

2 Detection Data: Template



ANALYSIS_PERIOD_START_DATETIME	ANALYSIS_PERIOD_END_DATETIME	ANALYSIS_PERIOD_EFFORT_SECOND	ANALYSIS_TIME_ZONE	SPECIES	PRESENCE	N_DETECTIONS	CALL_TYPE	DETECTION_METHOD	PROTOCOL_REFERENCE	DETECTION_SOFTWARE_NAME	DETECTION_SOFTWARE_VERSION	MIN_ANALYSIS_SAMPLING_RATE_H	MAX_ANALYSIS_SAMPLING_RATE_HZ	QC_PROCESSING
2006-01-06T00:00:00-05:00	2006-01-07T00:00:00-05:00	86400	UTC-5	EUGL	N	0	Upcall	LFDCS	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166)	IDL	8.5	0	2000	Archival
2006-01-07T00:00:00-05:00	2006-01-08T00:00:00-05:00	86400	UTC-5	EUGL	N	0	Upcall	LFDCS	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166)	IDL	8.5	0	2000	Archival
2006-01-08T00:00:00-05:00	2006-01-09T00:00:00-05:00	86400	UTC-5	EUGL	N	0	Upcall	LFDCS	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166)	IDL	8.5	0	2000	Archival
2006-01-09T00:00:00-05:00	2006-01-10T00:00:00-05:00	86400	UTC-5	EUGL	N	0	Upcall	LFDCS	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166)	IDL	8.5	0	2000	Archival
2006-01-10T00:00:00-05:00	2006-01-11T00:00:00-05:00	86400	UTC-5	EUGL	N	0	Upcall	LFDCS	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166)	IDL	8.5	0	2000	Archival

2.1 Detection Data: Field Definitions

COLUMN_NAME	DEFINITION	ENTRY OPTIONS	EXAMPLE
UNIQUE_ID*	A unique ID for the recorder on the metadata sheet that this detection data can be linked to. There should be only one unique ID for any recorder entered. For each UNIQUE_ID and SPECIES combination, there should be the same combination of values for all of the following fields: CALL_TYPE, DETECTON_METHOD, PROTOCOL_REFERENCE, and ANALYSIS_SAMPLING_RATE_HZ. If multiple values are used across one UNIQUE_ID and SPECIES for any of these fields marked with an asterisk (*), enter all values and separate with a semicolon (";")	Text string	NEFSC_SBNMS_200601_CH3_3
ANALYSIS_PERIOD_START_DATETIME	Start datetime of validated data analyzed, for the time scale of the analysis, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ) (i.e. the start date and time for the time bin of reporting right whales detected for that row of data); for daily presence, the start date would be the beginning date and time for that analysis day). Z in datetime refers to datetime stamps in UTC	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2021-01-01T00:00:00-05:00

	timezone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.		
ANALYSIS_PERIOD_END_DATETIME	End datetime of validated data analyzed, for the time scale of the analysis, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ) (i.e. the end for the time bin of reporting right whales detected for that row of data). Z in datetime refers to datetime stamps in UTC timezone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2021-01-02T00:00:00-05:00
ANALYSIS_PERIOD_EFFORT_MINUTES	The amount of time, in minutes, the effort occurred in. (i.e. if the first 5 minutes of every hour analyzed was looked at, this number would be 5)	Numeric	5
ANALYSIS_TIME_ZONE	The time-zone that the analysis was conducted in and that the time stamps in the ANALYSIS_PERIOD_START_DATETIME match (these may differ from the time zone of the sound files, for example if sound files are in UTC, but analysis was conducted on a local time zone, the analysis time zone would be UTC-5).	Text string	UTC-5
SPECIES*	The species for which analysis was conducted for and the detection "ACOUSTIC_PRESENCE" column pertains to. See Species Code section to find the appropriate code to use for each species.	See Species Code section below	EUGL
ACOUSTIC_PRESENCE	Whether the species was detected, possibly detected, not detected, or not analyzed for. Entry options: D, P, N, or M. "D" denotes a day with validated species' presence, "P" for days that cannot definitively confirm species' presence, "N" for no true detections, and "M" for data that has not been analyzed for that species' presence, or the data is missing (i.e. if no recordings are available for that time: use M here for data gap times within a deployment).	"D"; "P"; "N"; "M"	D

N_VALIDATED_DETECTIONS	The number of detections validated and found "true" during the analysis period. This column may be left blank if total true detections was not tallied for the analysis.	Numeric or NA	1
CALL_TYPE*	The call type used for the analysis period for the species' presence. Example: "Upcall", "Gunshot", "Moan" for right whales. If multiple call types were used, or there are multiple analysis being reported for the time period, add all call types, separated with a semicolon (";"). For example for blue whales, if both song and arch calls are being presented here, "A/B/AB song; Arch" should be used. If additional call types used that are not listed in ENTRY OPTIONS, please let nmfs.pacmdata@noaa.gov know upon submission so this field can be updated accordingly. Do not use commas in this field.	Upcall; Moan; Gunshot; 20Hz Pulse; Song; Social; Song & Social; A/B/AB song; Arch; Frequency modulated upsweep; Narrow band high frequency click; Pulse train	Upcall
DETECTION_METHOD*	How the data was reviewed for this species' presence, either "Manual" for hand browsing, or the detector used. For example, Manual, LFDCS, ISRAT, Pamguard Click Detector. If there is an available version of the detector, include here (e.g., ISRAT v3.5). If multiple detectors for this SPECIES and UNIQUE_ID were used, separate multiple entries with semicolon (";"). Do not use commas in this field.	Text string	LFDCS
PROTOCOL_REFERENCE*	Published reference, DOI, or link to documentation for the detector used, and/or analysis method. If not available, "Unpublished" should be used. Separate multiple entries with a semicolon (";") and have the DOI in parenthesis following Author Year (if available). Do not use commas in this field.	Text string	Baumgartner & Mussoline 2011 (doi:10.1121/1.3562166); Davis et al. 2017 (doi:10.1038/s41598-017-13359-3)
DETECTION_SOFTWARE_NAME	The software used for the detection method. This could be either the standalone software program (e.g., PAMGUARD, Raven), or the name of the programming	Text string	Matlab

	language the detection method was written in (e.g., IDL, MATLAB)		
DETECTION_SOFTWARE_VERSION	The version number of the software used, if applicable	Text string	2014b
MIN_ANALYSIS_SAMPLING_RATE_HZ	The minimum sample rate used for this analysis. Default value is 0 Hz. If middle frequencies were viewed for this analysis (i.e. 200-1000Hz), this value would be 200.	Numeric	0
MAX_ANALYSIS_SAMPLING_RATE_HZ	The maximum sample rate used for the analysis, in Hz. For example, if the original recordings had a sample rate of 48kHz, and the data was resampled to 2kHz for the analysis, then this value would be 2000.	Numeric	2000
QC_PROCESSING	Was the analysis conducted in real time (i.e. the recorder did not have to be retrieved for the analysis), or was analysis done post-processing (i.e. analysis done after the recorder was retrieved)?	"Real-time" or "Archival"	Archival

* Fields with an asterisk (*) should have the same combination of values across for all entries of that species for that UNIQUE_ID

2.2 Detection Data: Species Codes

COMMON_NAME	SCIENTIFIC_NAME	SPECIES_CODE
ATLANTIC SPOTTED DOLPHIN	Stenella frontalis	STFR
ATLANTIC WHITE-SIDED DOLPHIN	Lagenorhynchus acutus	LAAC
BELUGA WHALE	Delphinapterus leucas	DELE
BLAINVILLE'S BEAKED WHALE	Mesoplodon densirostris	MEDE
BLUE WHALE	Balaenoptera musculus	BAMU
BOTTLENOSE DOLPHIN	Tursiops truncatus	TUTR
BOWHEAD WHALE	Balaena mysticetus	BAMY
BRYDE'S WHALE	Balaenoptera edeni	BABR
CLYMENE DOLPHIN	Stenella clymene	STCL
CUVIER'S BEAKED WHALE	Ziphius cavirostris	ZICA
FIN WHALE	Balaenoptera physalus	BAPH

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GERVAIS' BEAKED WHALE	Mesoplodon europaeus	MEEU
HARBOR PORPOISE	Phocoena phocoena	PHPH
HECTOR'S DOLPHIN	Cephalorhynchus hectori	CEHE
HUMPBACK DOLPHIN	Sousa chinensis	SOCH
HUMPBACK WHALE	Megaptera novaeangliae	MENO
KOGIA SPECIES	Kogia Spp.	KOSP
DWARF SPERM WHALE	Kogia sima	KOSI
PYGMY SPERM WHALE	Kogia breviceps	KOBR
KILLER WHALE	Orcinus orca	OROR
MINKE WHALE (COMMON)	Balaenoptera acutorostrata	BAAC
NARWHAL	Monodon monoceros	MOMO
NORTH ATLANTIC RIGHT WHALE	Eubalaena glacialis	EUGL
SOUTHERN RIGHT WHALE	Eubalaena australis	EUAU
NORTH PACIFIC RIGHT WHALE	Eubalaena japonica	EUJA
NORTHERN BOTTLENOSE WHALE	Hyperoodon ampullatus	HYAM
OMURA'S WHALE	Balaenoptera omurai	BAOM
PANTROPICAL SPOTTED DOLPHIN	Stenella attenuata	STAT
PILOT WHALE	Globicephala Spp.	GLSP
PILOT WHALE (LONG-FINNED)	Globicephala melas	GLME
PILOT WHALE (SHORT-FINNED)	Globicephala macrorhynchus	GLMA
RISSO'S DOLPHIN	Grampus griseus	GRGR
ROUGH TOOTHED DOLPHIN	Steno bredanensis	STBR
SEI WHALE	Balaenoptera borealis	BABO
SHORT BEAKED COMMON DOLPHIN	Delphinus delphis	DEDE
SOWERBY'S BEAKED WHALE	Mesoplodon bidens	MEBI
SPERM WHALE	Physeter macrocephalus	PHMA
STRIPED DOLPHIN	Stenella coeruleoalba	STCO
TRUE'S BEAKED WHALE	Mesoplodon mirus	MEMI
WHITE BEAKED DOLPHIN	Lagenorhynchus albirostris	LAAL

3 Metadata: Template

UNIQUE_ID	PROJECT	DATA_POC_NAME	DATA_POC_AFFILIATION	DATA_POC_EMAIL	STATIONARY_OR_MOBILE	PLATFORM_TYPE	PLATFORM_NO	SITE_ID	INSTRUMENT_TYPE	INSTRUMENT_ID	CHANNEL	MONITORING_START_DATETIME	MONITORING_END_DATETIME	SOUNDFILES_TIMEZONE	LATITUDE	LONGITUDE	WATER_DEPTH_METERS	RECORDER_DEPTH_METERS	SAMPLING_RATE_HZ	RECORDING_DURATION_MINUTES	RECORDING_INTERVAL_MINUTES	SAMPLE_BITS	SUBMITTER_NAME	SUBMITTER_AFFILIATION	SUBMITTER_EMAIL	SUBMISSION_DATE
NEFSC_SBNMS_200601_C	NEFSC_SBNMS_200601_C	SofieVanParijs	NOAANEFSC	sofie.vanparijs@noaa	Stationary	Bottom-mounted	NA	3	MARU	82	3	2006-01-06T00:00:00-	2006-03-29T00:00:00-	UTC-5	42.4697	-70.2403	66.4	64.4	2000	60	0	16	GenevieveDavis	NOAANEFSC	genevieve.davis@noaa	2021-04-07T10:30:00-

H3_3	H3			.gov								05:00	05:00												.gov	05:00
NEFSC_SBNMS_200603_CH6_6	NEFSC_SBNMS_200603_CH6	SofieVanParijs	NOAANEFSC	sofie.vanparijs@noaa.gov	Stationary	Bottom-mounted	NA	6	MARU	98	6	2006-03-29T00:00:00-05:00	2006-05-24T00:00:00-05:00	UTC-5	42.6455	-70.3745	68	66	2000	60	0	16	GenevieveDavis	NOAANEFSC	genevieve.davis@noaa.gov	2021-04-07T10:30:00-05:00

3.1 Metadata: Field Definitions

COLUMN_NAME	DEFINITION	ENTRY OPTIONS	EXAMPLE
UNIQUE_ID	A unique ID for the recorder that the detection data can be linked to. There should be only one unique ID for any recorder entered.	Text string	NEFSC_SBNMS_200601_CH3_3
PROJECT	The name of the project or experiment	Text string	NEFSC_SBNMS_200601_CH3
DATA_POC_NAME	The name of the point of contact for the data (data POC)	Text string	Sofie Van Parijs
DATA_POC_AFFILIATION	The data POC's primary affiliation	Text string	NOAA NEFSC

DATA_POC_EMAIL	The data POC's email address	Text string	sofie.vanparijs@noaa.gov
STATIONARY_OR_MOBILE	Is the recorder moored (stationary) or moving (mobile)	"Stationary" or "Mobile"	Stationary
PLATFORM_TYPE	The type of platform the recorder is on. This is shown in the second drop down menu on PACM. Entry options for moored recorders: "Bottom-mounted", "Surface-buoy"; Entry options for mobile recordings: "Electric-glider", "Wave-glider", "Towed-array", "Linear-array", "Drifting-buoy", "Tag"	"Bottom-Mounted"; "Surface-buoy"; "Electric-glider"; "Wave-glider"; "Towed-array"; "Linear-array"; "Drifting-buoy"	Bottom-Mounted
PLATFORM_NO	ID or number of the platform (such as an independent, dedicated mooring or glider) a recorder is deployed on, if applicable. For example, a Slocum glider's platform ID: we04. For SoundTrap 500s, this would be the serial number of the recording unit (not the serial number of the hydrophone)	Text string	we04
SITE_ID	The site or station ID. For example, a line of three recorders off Cape Hatteras might have the following individual site IDs: H1, H2, and H3	Text string	H3
INSTRUMENT_TYPE	Recording instrument type if available, or hydrophone manufacturer. Examples: DMON, AMAR, MARU, HARP, SoundTrap, HTI, APC	Text string	MARU
INSTRUMENT_ID	Serial or unit ID number of the recording instrument or hydrophone. In the case of SoundTrap500s, this would be the hydrophone serial number	Text string	82
CHANNEL	The recording channel. Single channel data would be entered as 1.	Numeric	3
MONITORING_START_DATETIME	The start datetime in ISO8601 format (YYYY-MM-DDThh:mm:ssZ) for the start of usable data for that deployment (i.e. the recorder is on and in the water). Z in datetime refers to datetime stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2006-01-06T00:00:00+05:00
MONITORING_END_DATETIME	The end datetime, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ), for the end of usable data for that deployment (i.e. the recorder is off or no longer in the	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2006-03-29T00:00:00+00:00

	water). Z in datetime refers to datetime stamps in UTC time zone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.		
SOUNDFILES_TIMEZONE	The time zone the sound files are in, with relation to UTC (i.e. EST would be entered as UTC-5)	Text string	UTC-5
LATITUDE	Latitude of recorder, in decimal degrees (DD). For mobile data, this field will be blank and will refer to the GPS submitted data instead.	Numeric in DD	42.4697
LONGITUDE	Longitude of recorder, in decimal degrees (DD). For mobile data, this field will be blank and will refer to the GPS submitted data instead.	Numeric in DD	-70.2403
WATER_DEPTH_METERS	Water depth (in meters) where the recorder is located (may be blank for mobile data)	Numeric	66.4
RECORDER_DEPTH_METERS	Depth of the recorder (in meters) in the water column (may be blank for mobile data)	Numeric	64.4
SAMPLING_RATE_HZ	Sampling rate of raw sound recordings, in Hz	Numeric	2000
RECORDING_DURATION_MINUTES	Recording schedule: the amount of time, in minutes, the recorder is on and recording. For continuous recordings, this entry will be "60" (and the following field RECORDING_INTERVAL_MINUTES will be "0"). For duty cycled data, this is the amount of time the recorder is turned "on" for. If the first 10 minutes of every hour is recorded, then RECORDING_DURATION_MINUTES is "10" and RECORDING_INTERVAL_MINUTES is "50"	Numeric	60
RECORDING_INTERVAL_MINUTES	Recording schedule: the amount of time, in minutes, the recorder is not recording within the recording cycle. For continuous recordings, this entry will be "0" and the RECORDING_DURATION_MINUTES field will be "60". For duty cycled data, this is the amount of time the recorder is turned "off" for. If the first 10 minutes of every hour is recorded, then RECORDING_DURATION_MINUTES is "10" and RECORDING_INTERVAL_MINUTES is "50"	Numeric	0
SAMPLE_BITS	The sample bit rate of recordings, if known	Numeric	16
SUBMITTER_NAME	Name of who is submitting the data	Text string	Genevieve Davis

SUBMITTER_AFFILIATION	Primary affiliation of who is submitting the data	Text string	NOAA NEFSC
SUBMITTER_EMAIL	E-mail of who is submitting the data	Text string	genevieve.davis@noaa.gov
SUBMISSION_DATE	The date the data is being submitted or was compiled in ISO8601 format (YYYY-MM-DDThh:mm:ssZ). Z in datetime refers to datetime stamps in UTC timezone. See https://en.wikipedia.org/wiki/ISO_8601 for further information on ISO8601 formats and time zones.	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2021-08-02T04:01:00-05:00

4 GPS Data (mobile data only): Template

UNIQUE_ID	DATETIME	LATITUDE	LONGITUDE
NEFSC_GU1803	2018-07-21T19:00:00+00:00	39.88628	-69.80726
NEFSC_GU1803	2018-07-21T20:00:00+00:00	39.837455	-69.76746
NEFSC_GU1803	2018-07-21T21:00:00+00:00	39.756474	-69.69761
NEFSC_GU1803	2018-07-21T22:00:00+00:00	39.670523	-69.62628
NEFSC_GU1803	2018-07-21T23:00:00+00:00	39.58242	-69.55322
NEFSC_GU1803	2018-07-22T00:00:00+00:00	39.537873	-69.51541
NEFSC_GU1803	2018-07-22T10:00:00+00:00	40.022571	-67.93882
NEFSC_GU1803	2018-07-22T11:00:00+00:00	40.056798	-67.88413
NEFSC_GU1803	2018-07-22T12:00:00+00:00	40.048351	-67.89558
NEFSC_GU1803	2018-07-22T13:00:00+00:00	40.076441	-67.77436

4.1 GPS Data: Field Definitions

COLUMN_NAME	DEFINITION	ENTRY OPTIONS	EXAMPLE
UNIQUE_ID	The unique ID for the recorder that the detection data can be linked to: there should be only one UNIQUE_ID for any recorder entered	Text string	NEFSC_GU1803
DATETIME	The date and time that corresponds with the GPS coordinate, in ISO8601 format (YYYY-MM-DDThh:mm:ssZ). For mobile detection data, there should be a position that can correspond to every row in the detection data	DATETIME in format YYYY-MM-DDThh:mm:ssZ	2018-07-21T19:00:00Z
LATITUDE	Latitude position in Decimal Degrees	Numeric in format DD	39.88628

LONGITUDE	Longitude position in Decimal Degrees	Numeric in format DD	-69.7674575