INCORPORATING PASSIVE ACOUSTIC MONITORING DATA INTO OBIS-SEAMAP: A STRATEGY TO ENHANCE MARINE MAMMAL CONSERVATION

by
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INDEX

I. ABSTRACT

Over 60 species of marine mammals reside in United States waters. Assessing each marine mammal stock in the United States is a lengthy, expensive, and complicated task. The use of new technologies, such as passive acoustic monitoring, could help to improve marine mammal survey efforts and decrease data fragmentation. Passive acoustics are particularly useful for monitoring cetaceans in remote areas or in periods of poor weather or darkness.

OBIS-SEAMAP, a web-based archive of geo-referenced marine mammal, sea turtle, and sea bird datasets, has established a passive acoustic monitoring initiative as a strategy to enhance marine mammal conservation. The initiative will integrate acoustic data into the archive, which currently contains data collected from traditional visual surveys and telemetry. Acoustic methods can improve the ability to detect and monitor many deep-diving, highly migratory, and cryptic marine mammal species (Burtenshaw et al, 2004). However, challenges associated with geographical representation of acoustic recordings need to be addressed prior to data integration into OBIS-SEAMAP. This paper aims to identify some of these difficulties, including localizing cetaceans spatially in two and three dimensions, species identification, and encouraging collaborative participation from marine mammal researchers. Recommendations have been made to improve data collection methods and the process of incorporating acoustic data into SEAMAP.

II. INTRODUCTION

The Consortium of Oceanographic Research and Education (CORE) initiated the Census of Marine Life (CoML) program in partnership with the Alfred P. Sloan Foundation and the National Oceanographic Partnership Program (Halpin et al, 2006). Founded in 1997, CoML is an innovative non-profit network of 70 nations that are committed to increasing the biogeographic and ecological understanding of marine systems, interactively exploring ocean life, and conserving marine biodiversity (CORE, 2006). An important component of the Census of Marine Life is the Ocean Biogeographic Information System (OBIS), an information database that provides global geo-referenced biogeographic data for marine species (Halpin et al, 2006).

A major data provider to the digital OBIS catalog is Spatial Ecological Analysis of Megavertebrate Populations (SEAMAP). Currently funded by the National Science Foundation, OBIS-SEAMAP is a web-based archive that allows public access to geo-referenced observations of marine mammals, sea turtles, and seabirds at http://seamap.env.duke.edu (Read et al, 2008). As the principal institutional home of OBIS-SEAMAP, Duke University has taken an active role in data collection and public outreach since the start of the program in 2002. Project objectives include quantifying global distribution of marine mammals, modeling marine biodiversity, and assessing the status of threatened and endangered species.

To date, OBIS-SEAMAP contains 215 archived datasets with observations of 511 species of marine birds, turtles, and mammals. Most of these data were collected using traditional field techniques, such as visual line-transects or telemetry. Records currently exist for 49 species of cetaceans, which accounts for only 58% of the 84 cetacean species known to inhabit the world's oceans (Read et al, 2008). Datasets in OBIS-SEAMAP contain detailed metadata that are consistent for the entire database: dataset identification number, number of records, begin and start date, minimum and maximum longitudes and latitudes, platform, effort, upload date, an abstract, statement of purpose, and contact information (Read et al, 2008). Each dataset can be viewed as an online map, a Google Earth KML file, or a WMS GIF image. Map legends allow viewers to easily identify different species, determine bottom bathymetry of the survey site, and view the vessel cruising speeds, survey tracks, and survey perimeter. Individual datapoint labels are viewable with Google Earth and provide details of sighting records, including the date, time, geographical coordinates, and observation count of a sighting event. Occurrence of each species is represented with a unique color-coded circle.

Current contributors to OBIS-SEAMAP include 16 organizations in the United States, 6 in the United Kingdom, 2 in Canada, and 1 each in the Bahamas and Peru (Read et al, 2008). Within the United States, 15 contributors to OBIS-SEAMAP are public sector organizations. Data providers include the NOAA Southwest, Southeast, Northeast, and Alaska Fisheries Science Centers, the National Marine Mammal Laboratory, the Mineral Management Service of the United States Department of the Interior, and the National Science Foundation. State institutions, such as the Washington Department of Fish and Wildlife and universities from Rhode Island, North Carolina, Maine, and Georgia comprise 9 of the remaining public sector groups.

These public sector groups from the United States contributed data within and outside of U.S. territorial waters. For example, studies undertaken by United States researchers on marine mammals in international waters include a 2003-2004 National Marine Fisheries Service survey in the Indian Ocean that returned records for 12 cetacean species and a 1992-1993 University of Southern Maine-The Years of the North Atlantic Humpback Whale survey of humpbacks spanning the North Atlantic Ocean.

Only 1 of the 16 organizations from the United States, the Cascadia Research Collective, contributed as a private sector group. Cascadia Research was founded in Washington State in 1979 as a non-profit organization dedicated to marine mammal research and education. The Cascadia dataset includes sightings records for endangered blue whales along the northeastern Pacific coastline from 1972 to 2004.

OBIS-SEAMAP actively encourages the application of new technologies to supplement these existing datasets and increase the quantity and quality of data collected worldwide. SEAMAP is currently exploring a new passive acoustic monitoring initiative to enhance marine mammal data holdings through new technologies, such as acoustic recording devices. While there are many advantages to acoustic methods over traditional visual surveys, representing acoustic recordings as geo-referenced data on the OBIS-SEAMAP server is an intricate process.

This paper reviews some of the challenges associated with integrating passive acoustic monitoring data into OBIS-SEAMAP. These include the issues of collaboration within the United States and internationally, the differing acoustic abilities of mysticetes and odontocetes, and the challenge of uploading data collected from various acoustic recording devices.

III. MARINE MAMMAL ACOUSTIC ECOLOGY

Cetaceans within the sub-orders Odontoceti (the toothed whales) and Mysticeti (the baleen whales) use sound as a primary sense for communication, social interaction, navigation, and detection of predators and prey (National Research Council, 2000). Odontocete vocalizations are characterized by high-frequency noises ranging from <10 Hz to >200 kHz, while mysticete vocalizations are typically less than 10 kHz (National Research Council, 2003).

Turbid coastal areas and deep open ocean waters are often too dark or murky to use visual cues for locating prey, conspecifics, and predators. As a result, odontocetes use both passive listening and active sound production for detecting objects and navigation. Unique signature vocalization patterns allow for species identification from these sounds (National Research Council, 2003). The acoustic abilities of three odontocete species, bottlenose dolphins (*Tursiops truncatus*), killer whales (*Orcinus orca*), and sperm whales (*Physeter macrocephalus*), are provided here as examples.

The use of echolocation by bottlenose dolphins varies by geographical region, activity type, and group size. For instance, bottlenose dolphins in Sarasota Bay, Florida, consistently use echolocation less than bottlenose dolphins in coastal waters of North Carolina (Gannon et al, 2005). Vocalization rates also vary with time of day, and are generally linked to coordinated predation efforts and prey type (Lammers and Au, 2003).

Like other delphinids, vocalizations of killer whales (*Orcinus orca*) vary in relation to activity, prey, and geographic location. Some whales reside in cold waters with poor visibility and short periods of daylight, and rely on sound for intraspecific recognition, socialization, and maintenance of group cohesion (Simon et al, 2007). In the northeastern Pacific, transient killer whales forage on marine mammals, while resident killer whales forage primarily on salmon (Simon et al, 2007). Transient killer whales produce sound infrequently while foraging so as not to alert their marine mammal prey (Deecke et al, 2005). In contrast, resident killer whales in the northern Pacific and killer whales in Iceland and Norway use frequent echolocation while foraging to locate fish prey, which cannot detect these high frequency sounds (Barrett-Lennard et al, 1996).

Sounds produced by sperm whales (*Physeter macrocephalus*) are highly distinctive and identifiable (Sparks et al, 1993). Sperm whales produce a repetitive series of clicks, which last an average of 2 to 24 milliseconds, and are divided into four categories: usual clicks, creaks, slow clicks, and codas (Morrissey et al, 2006). Sperm whales use slow clicks and codas to communicate and usual clicks and creaks for echolocation. Measuring the time between clicks is an effective way to identify individual sperm whales because of the characteristic interval time between clicks, which is different for each animal (Morrissey et al, 2006).

Unlike odontocetes, mysticetes do not echolocate. The acoustic abilities of two mysticete species, humpback whales (*Megaptera novaeangliae*) and blue whales (*Balaenoptera musculus*), are provided as examples. Female humpback whales do not sing, but male humpbacks vocalize continuously for hours or multiple days while on breeding grounds (Swartz et al, 2001). Male humpback songs are composed of several themes that are possibly used to attract females, display territoriality or aggression, and locate other males during the winter breeding season (Swartz et al, 2001).

Unlike the well-studied humpback whale, less is known about the acoustic behavior of the blue whale. Blue whale vocalizations are grouped into two categories, which differ temporally and spatially. Male blue whales typically produce a low-frequency continuous song when traveling, which can last for hours at a time (Oleson et al, 2007). The song is characterized by pulses and long-duration tones, and may be used for long distance signaling to other blue whales (McDonald et al, 2001). Males sing primarily during the breeding season between November and December, and display geographic variability in the length and production of their songs (Clarke and Charif, 1998). The second type of blue whale vocalization is a variable downswept call, which is produced by both males and females between foraging events (Oleson et al, 2007). The variable calls may be used to communicate with or respond to other blue whale calls (McDonald et al, 2001).

Identification of cetacean species from recordings is typically based on comparison of the acoustic recordings to spectrographic images of sound sequences typical to animals commonly found within the study area (Clark and Altman, 2006). Several data loggers and software packages have been developed to automate and expedite the collection, organization, and analysis of passive acoustic data, including Logger, Rainbow Click, Porpoise, Spectralab, Whistle, NMEA Server, ADC Pipe, and MonDB (Lewis et al, 1999). Each program is specialized for the detection of a different frequency range. For example, Porpoise is designed to detect the high-frequency vocalizations of harbor porpoises and other small cetaceans, while Rainbow Click and Whistle are designed to detect the medium-frequency vocalizations produced by sperm whales, pilot whales, dolphins, killer whales, and other toothed whales (Lewis et al, 1999).

IV. OBIS-SEAMAP PASSIVE ACOUSTIC MONITORING INITIATIVE

In an effort to increase the number of datasets and participating organizations, OBIS-SEAMAP has begun a passive acoustic monitoring initiative. The ultimate goal of the initiative is to advance the current spatial representation of global marine mammal distribution with innovative research methods. The initiative will integrate spatial data obtained from passive acoustic recording devices into the existing SEAMAP archive.

Incorporating passive acoustic monitoring data into OBIS-SEAMAP is expected to help address some of the biases inherent in visual surveys. Acoustic monitoring devices provide several advantages over visual surveys, including reliable 360 degree monitoring of a large area of water for 24 hours per day during all types of weather conditions (Lewis et al, 1999). Passive acoustic monitoring is particularly useful in remote locations, in waters with poor visibility, and areas where traditional field observations are not possible (Halpin and Read, 2006). Adverse weather conditions, such as wind, fog, rain, dim light, and sea swell decrease visual detection rates and may produce survey biases (Moore et al, 2006). Furthermore, individual surveyors are limited by their ability to watch only a small portion of surface waters at a time. As such, visual surveys require a large team of scientists actively watching for cetaceans over extended periods of time.

Visual observation methods are best suited for studies on non-vocal animals and animals that surface frequently (Oleson et al, 2007). Conversely, passive acoustic recording devices are beneficial for studies on cetaceans that may be difficult to sight and deep diving animals, such as sperm whales that make prolonged feeding dives (Lewis et al, 1999). Acoustic surveys are particularly useful for highly migratory species, such as blue whales, because it is difficult to characterize their large scale seasonal movements using traditional visual surveys (Burtenshaw et al, 2004). The use of passive acoustic monitoring devices has resulted in improved detection rates of several species of whales, including humpback whales, blue whales, fin whales, and right whales (Oleson et al, 2007). Acoustic calls of these mysticetes have been detected by hydrophones located tens of kilometers away from the source animal (Clark and Fristrup, 1997).

Acoustic methods have also yielded higher detection rates than visual methods for many odontocete species, such as bottlenose dolphins and sperm whales (Simon et al, 2007). Bottlenose dolphins have been detected by hydrophones at a distance of up to 2.5 km, which is a significantly greater distance than could be detected through visual surveys (Embling et al, 2005). When using towed acoustic arrays, sperm whales have been detected as far away as 18 km (Sparks et al, 1993). Sperm whale detection rates increased significantly when using acoustic monitoring devices because of the long dive durations and regular clicking behavior throughout the duration of deep dives than cannot be observed from the surface (Barlow and Taylor, 2005).

Several types of passive acoustic monitoring devices are used for marine mammal studies, including high-frequency acoustic recording packages (HARPs), low-frequency acoustic recording packages (ARPs), fixed hydrophone arrays, towed arrays, and porpoise detectors (T-PODS). Permanently moored to the seafloor, high-frequency recording packages (HARPs) have the capacity to continuously record acoustic data for up to 2 months, or if programmed to record at intervals, up to six months (Wiggins and Hildebrand, 2007). HARPs contain a single hydrophone capable of detecting sounds from 10 Hz to 100 kHz, but are usually programmed to record only the higher frequencies to increase accuracy (Johnston et al, 2007). Cetacean sounds detectable by HARPs include sperm whale clicks and delphinid whistles, pulses, and clicks (Soldevilla et al, 2006).

Low-frequency recording packages (ARPs) are bottom-mounted recording stations that contain one hydrophone tethered high above the seafloor. ARPs are capable of recording sounds up to 1 kHz continuously for up to 400 days (Moore et al, 2006). Baleen whale calls occur at very low frequencies, and therefore can only be recorded using a low-frequency package. For example, Pacific blue whale B calls are emitted at approximately 18 Hz, which falls within the recording range of a typical ARP (Wiggins, 2003).

Moored hydrophone arrays, such as those that measure earthquakes during long-term seismic surveys, have the capability of detecting the low-frequency calls of baleen whales (Nieukirk et al, 2004). These and other such low-frequency autonomous arrays have detected blue whales over a sizable range, in some cases up to 500 km away (Watkins et al, 2000). The most consistent average mysticete detection range is from 20-40 km away (Burtenshaw et al, 2004).

Moving vessels provide a platform for acoustic data collection over a larger area than is often possible by stationary recording packages or hydrophone arrays. Towed arrays typically consist of three or more hydrophones evenly spaced along a cable. Low-frequency hydrophones are generally spaced at distances as far apart as 500 m (Clark and Altman, 2006), while high-frequency hydrophones are typically spaced as close as 11 m apart (Lammers et al, 2003). Both configurations allow for localization of a sound-producing animal based on the vessel coordinates and an analysis of the time differences of arrival at each hydrophone (Clark and Altman, 2006). Such vessels operate at cruising speeds greater than 4 knots to maintain accuracy (Nielsen and Mohl, 2006).

Directional sonobuoys may be hull-mounted or towed. These sonobuoys have the capability of recording data for up to 8 hours (Branch et al, 2007). Within a sonobuoy, specialized directional sensors record sound bearings and amplitudes. From this information, accurate geo-references of vocalizing animals can be determined.

Porpoise detectors (T-PODs) are self-contained packages containing a hydrophone and submersible computer (Thomsen et al, 2005). These automated devices, which can be towed or statically deployed, record, analyze, and identify high-frequency cetacean clicks over a radius of 170 m (Carstensen et al, 2006). As such, T-PODs are designed for small-scale or site-specific surveys, including recent studies on the impacts of offshore wind farm construction on harbour porpoise habitat use (Carstensen et al, 2006). T-PODS have also been used extensively to identify the extent to which pingers affect dolphin behavior in association with commercial fishing gear (Leeney et al, 2007).

V. CHALLENGES OF INTEGRATING PASSIVE ACOUSTIC MONITORING DATA INTO OBIS-SEAMAP

Although there are many benefits of using passive acoustic monitoring to study marine mammal distribution, incorporating data derived from acoustic sampling into OBIS-SEAMAP presents many challenges. Challenges include detection, species identification, localization, and encouraging collaborative participation from marine mammal researchers around the globe.

Each recording package has an obvious set of limitations based on its design to record either high or low-frequency sounds. HARPs and T-PODs are valuable for detecting the high-frequency whistles and clicks, and may miss recording baleen vocalizations, while with low-frequency devices, the capabilities are reversed.

The difficulty of identifying certain species and individuals within a species from acoustic recordings presents another challenge to the passive acoustic monitoring initiative. While many species, such as sperm whales and bottlenose dolphins, produce signature vocalizations, other species produce more homogeneous or indistinguishable sounds. Species identification is particularly challenging for rare species for which calls have not been previously recorded (Embling, 2005). Furthermore, it is often difficult to identify the group size of animals from an acoustic recording, particularly if a solitary animal is making multiple calls or several animals are each making a single call (Nieukirk, 2004). Passive acoustic techniques obviously do not detect silent animals, so acoustic observations may not provide a complete picture of distribution for non-vocal species.

Accurate geo-referencing is an essential prerequisite for every dataset in the SEAMAP archive. Advanced statistical software packages analyze the respective time differences of arrival, run a hyperbolic positioning algorithm, and calculate the geographic location of an animal from the spectrograms of three or more hydrophones (Morrissey et al, 2006). These hydrophones must be spaced in close enough proximity to overlap detection ranges, approximately 10 km for low-frequency recorders and less for high-frequency recorders (Branch et al, 2007). The use of three hydrophones can result in a horizontal geo-reference, whereas four hydrophones are needed to determine depth (Morrissey et al, 2006). Solitary acoustic devices are incapable of rendering a geo-reference, particularly without detailed information on certain parameters, including the sound propagation properties of the water column, basin topography, ambient noise levels, and water depth (Branch et al, 2007).

Unlike bottom-mounted hydrophones, most towed arrays are capable of determining a spatial reference for a vocalizing animal, particularly when vessels deploy two or more directional sonobuoys (Swartz et al, 2001). However, vessel and wave noise may decrease recording quality. Survey biases may exist if towed arrays are not used year-round, inter-annually, during inclement weather, or at night.

In addition to computer-based challenges, difficulties arise when considering the large dependency that SEAMAP has on the contribution of data from outside researchers. The ultimate success of the OBIS-SEAMAP passive acoustic monitoring initiative is limited by the willingness of individual researchers and institutions to make their data publicly available and the budgetary constraints of purchasing acoustic monitoring devices.

VI. RECOMMENDATIONS FOR THE FUTURE OF OBIS-SEAMAP

A major aim of OBIS-SEAMAP is to accurately represent the spatial and temporal distribution of marine mammals around the globe. To meet the goals of the acoustic initiative, the benefits of utilizing passive acoustic monitoring, including the capability of recording long-term continuous seasonal and temporal data during all weather conditions and in remote study sites, must be consistent with the methods in which the data is represented in the SEAMAP archive. The following recommendations are designed to address the challenges associated with integrating passive acoustic monitoring data into OBIS-SEAMAP, including updating the search query, encouraging the use of dual survey methods, emphasizing the need for geo-referenced data, and adding a three-dimensional mapping component to the archive.

Because of behavioral differences between cetacean species and seasonal variations in vocalization patterns, employing dual methods of visual line-transect surveys and passive acoustic monitoring will likely yield the highest detection rates and decrease survey bias when studying most cetacean species (Oleson et al, 2007). For instance, using passive acoustic monitoring devices to study the behavior and distribution of cetaceans, such as killer whales that live in remote offshore regions, is most effective when combined with other survey techniques (Simon et al, 2007). Although challenging and costly to use both survey methods, it is recommended that visual methods be used in conjunction with acoustic methods during portions of the year when acoustic methods alone cannot accurately detect species presence due to seasonal behavioral changes of targeted species. There is also a great potential to link the observations from visual and acoustic surveys within the SEAMAP archive.

Whenever possible, researchers should be able to provide the two-dimensional geographic coordinates of each detected cetacean. As such, it is encouraged that acoustic surveys involve the use three or more stationary hydrophones moored within overlapping detection range of one another for two-dimensional geo-references, or four hydrophones tethered at varying depths for three-dimensional localizations. Towed arrays should, when possible, involve the use of at least two directional hydrophones.

The current OBIS-SEAMAP archive has dataset browsing capabilities with search criteria selectable for data platform and taxa. Four platforms currently exist in the archives, including data collected by boat, plane, shore, and tag. One additional platform, acoustics, must now be added to the query. An additional selection option could be added to provide further clarity as to the type of acoustic device used in a study.

VII. 2008 PASSIVE ACOUSTIC MONITORING WORKSHOP

OBIS-SEAMAP convened a workshop, entitled *Incorporating Passive Acoustic Monitoring Data into OBIS-SEAMAP 2.0*, at the Duke University Marine Laboratory from April 16-17, 2008. The workshop was designed to review existing datasets, discuss solutions to data integration challenges, and make recommendations for the future of OBIS-SEAMAP. Hosted by Duke University Marine Laboratory faculty member and SEAMAP principle investigator Dr. Andrew Read, the workshop was attended by 18 marine acousticians. A full list of participants is given in Table 1.

Several case studies were presented by workshop participants to review current passive acoustic monitoring efforts. Such efforts included studies by the NOAA Pacific Islands Fishery Science Center that employ HARPs and towed arrays, the NOAA Northeast Fisheries Science Center with pop-ups and towed arrays, Woods Hole Oceanographic Institution with automated buoys, Duke University with towed arrays, and the Naval Underwater Warfare Center with

HARPs. These datasets will be incorporated into SEAMAP as prototypes to test the capabilities and compatibility of the archive.

Discussion topics included two-dimensional localization, dealing with uncertainty, incorporating vocalization type, representing long-term and short-term records from stationary and mobile sites, and capturing information from real-time monitoring systems. The result of the workshop is a set of recommendations for incorporating passive acoustic monitoring data into the SEAMAP archive. The following recommendations are consistent with a primary goal of OBIS-SEAMAP, to make geo-referenced observations of marine mammals available to a wide audience, and represent a consensus facilitated by group discussion:

1. OBIS-SEAMAP should store representative geo-referenced data on the occurrence of vocalizing cetaceans detected by a variety of monitoring systems. In addition, consideration should be given to presenting representative recordings and spectrograms. Access to these geo-referenced data will remain unrestricted and will be searchable by species or date range, as is the use for other data types.
2. Acoustic data should be represented as a rate of the number of dives, clicks, or other vocalizations recorded in a given time period. Additional information should be included for each study, including detector type, frequency range, and an example of the raw data.
3. When available, acoustic data should be coupled with other data types, including visual surveys and photo-identification records, and environmental data. Complimentary sound files should be linked to outside sources, such as the Macaulay Library at Cornell University.

4. All studies contain some level of uncertainty that should be addressed in the metadata. Special notice should be given in cases where uncertainty cannot be measured or the level of uncertainty is unknown. For example, it is impossible to measure the uncertainty embedded in some historical data, and as such that data has an unlimited bias that should be clearly identified in the metadata. Historical data and studies with unknown levels of uncertainty should be used to capture broad-scale patterns of distribution only. If known, uncertainty should be represented as a single generic level for a whole dataset.
5. Studies that are unable to distinguish vocalizations at the species level should use a taxonomical hierarchy to label animals at the lowest possible level.
6. If localization of an animal is not possible, the device position at the time of detection should serve as the position of the animal. A species-specific buffer should be applied to recognize a range of possible animal locations.
7. For educational value, SEAMAP should provide information comparing acoustic and visual sampling techniques. Such information should include differences in the methods of data collection and analysis, and the limitations of each acoustic monitoring device.
8. In addition to cetacean acoustics, SEAMAP will consider housing data from sirenian and pinniped acoustic surveys in the future.

Table 1: OBIS-SEAMAP Acoustic Monitoring Workshop Participant List

Participant	Organization
Jack Bradbury	Cornell University
Chris Clark	Cornell University
Ei Fujioka	Duke University
Doug Gillespie	University of St. Andrews
Bob Gisiner	Marine Mammal Commission
Pat Halpin	Duke University
Lucie Hazen	Duke University
Dave Johnston	NOAA
Erin LaBrecque	Duke University
Dave Mellinger	Oregon State University
Sue Moore	NOAA
Dave Moretti	Naval Underwater Warfare Center
Doug Nowacek	Florida State University
Sofie van Parijs	NOAA
Andrew Read	Duke University
Denise Risch	NOAA
Len Thomas	University of St. Andrews
Peter Tyack	Woods Hole Oceanographic Institution
Lynne Williams	Duke University

VIII. CONCLUSION

The marine environment is dynamic and complex, and therefore there is a need for in-depth multidisciplinary research. A wide range of marine ecosystems have been explored around the globe, with the emphasis of science moving toward conservation and species management. New management protocols and policies can be made only after accurately assessing the status of vulnerable, threatened, and endangered species. By determining an accurate representation of the distribution of marine mammals, anthropogenic influences such as shipping, commercial fisheries, and tourism, can be managed more effectively (Halpin et al, 2006).

By considering the challenges presented and using the recommendations offered in this paper, passive acoustic monitoring data can be integrated more seamlessly into OBIS-SEAMAP. Incorporating passive acoustic monitoring data into the OBIS-SEAMAP network will enhance global collaboration of marine mammal research and conservation. Using the best possible science to describe the global distribution of marine mammals is an important step in the marine mammal management process.

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