Chapter 1: Ecosystem background and project activities
Final Report to the Maryland Department of Natural Resources and the Maryland Energy Administration, 2015

Iain J. Stenhouse[1], Kathryn A. Williams[1], Emily E. Connelly[1], Sarah M. Johnson[1], Andrew T. Gilbert[1], Holly F. Goyert[2], and M. Wing Goodale[1]

[1]Biodiversity Research Institute, Portland, ME
[2]Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC

Project webpage: *www.briloon.org/mabs*

Suggested citation: Stenhouse IJ, Williams KA, Connelly EE, Johnson SM, Gilbert AT, Goyert HF, Goodale MW. 2015. Ecosystem background and project activities. In: Baseline Wildlife Studies in Atlantic Waters Offshore of Maryland: Final Report to the Maryland Department of Natural Resources and the Maryland Energy Administration, 2015. Williams, KA, Connelly, EE, Johnson, SM & Stenhouse, IJ (Eds.) Report BRI 2015-17, Biodiversity Research Institute, Portland, Maine. 19 pp.

Acknowledgments: This material is based upon work supported by the Maryland Department of Natural Resources and the Maryland Energy Administration under Contract Number 14-13-1653 MEA, and by the Department of Energy under Award Number DE-EE0005362.

Disclaimers: The statements, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the Maryland Department of Natural Resources or the Maryland Energy Administration. Mention of trade names or commercial products does not constitute their endorsement by the State.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

The state of Maryland has a significant swath of oceanic waters off its eastern shore. These waters, as well as the rest of the Mid-Atlantic region, are used by a broad range of marine wildlife species across the entire annual cycle. This is due in part to relatively high levels of primary productivity, high levels of seasonal variation in environmental conditions, and the region's central location on the edge of the continent (placing it within migratory routes for many taxa). Thus, it is essential to understand the dynamics of this ecosystem in order to manage it effectively, particularly with regard to anthropogenic stressors, such as offshore development. The Mid-Atlantic Baseline Studies (MABS) Project and Maryland Project, described here, provide two years of intensive survey data and other information (2012-2014) to improve our understanding of this ecosystem.

The study area included waters on the Outer Continental Shelf off the coasts of Delaware, Maryland, and Virginia between the state-federal boundary (5.6 km from shore) and the 30 m isobath. Offshore of Maryland, the study area also extended westward to the shoreline to include state waters. This region is characterized by a relatively flat, gently sloping sea floor, with sandy shoals along the inner continental shelf interspersed with smaller patches of other benthic habitats. The cool Labrador Current and warmer Gulf Stream collide in the Mid-Atlantic, and the region also exhibits a strong seasonal cycle in sea surface temperatures and salinity, with large volumes of fresh water emptying onto the shelf via the Hudson Estuary, Delaware Bay, and Chesapeake Bay. Seasonal stratification on the shelf and nutrient influxes from the bays drive much of the primary productivity in the region, and are thus strong influences on the distributions of wildlife and the characteristics of this ecosystem.

Methods employed in this study included boat surveys and high resolution digital video aerial surveys. This is the first study to use high resolution digital video aerial surveys on a large scale in North America, as it is a relatively new method for collecting distribution and abundance data on animals in the marine ecosystem. Boat-based and digital video aerial surveys each showed distinct benefits in detecting different taxa. Digital aerial surveys have the added advantage of being auditable and archivable, and include an extensive quality assurance process, which may lead to a greater degree of reliability in species identifications. The safety and speed with which digital aerial surveys can be conducted also make this approach attractive in the offshore environment, and the capabilities of digital aerial surveys will likely continue to improve with technological advances in the field. Boat surveys can provide detailed behavioral data, had generally better rates of identification of animals to species, and the analytical approaches for boat survey data are well established. Due to these respective strengths, integrating data from both survey approaches was in some cases the most effective means of filling data gaps and describing wildlife distributions in the Mid-Atlantic and Maryland study areas. Several analytical approaches were used in this study, including several approaches for integrating boat and aerial survey data, and the advantages and disadvantages of these approaches are also discussed.

Ecosystem background

The interactions among biota (e.g., organisms, populations, and communities) and abiota (i.e., the physical environment) comprise an ecosystem. The study of ecology attempts to identify these critical connections between organisms and their environment, and explain how those relationships affect, or are impacted by, the physical attributes of their habitats. Establishing baseline ecosystem function and identifying areas of important habitat and high species biodiversity is crucial to wildlife management.

For the last few decades there has been wide recognition that traditional methods of resource management, where management actions or environmental assessments target a single population, species, or issue, are extremely limiting or potentially misleading (Ehler and Douvere, 2009). Since the 1990s, management and regulatory agencies have increasingly recognized the importance of addressing research, conservation, and planning at the ecosystem scale (Christensen et al., 1996; Grumbine, 1994). Despite this fundamental shift in our collective thinking, however, few research studies are conducted at broad enough geographic or temporal scales to provide the data necessary to fully understand the complex relationships between species and their dynamic physical environments (Arkema et al., 2006; Leslie and McLeod, 2011; Ruckelshaus et al., 2008). In general, our narrow understanding of these relationships hinders the development and implementation of large-scale, ecosystem-wide management strategies, as well as the prediction of responses of species to broad environmental shifts brought about by anthropogenic activities and climatic change (Griffies, 2004; Tallis et al., 2010).

Marine ecosystems are particularly complex and dynamic assemblages that involve a variety of co-evolved species. Thus, research studies integrated across taxonomic groups and among trophic levels are critical to understanding marine ecosystem processes and mechanisms (Wiebe et al., 2009). To date, marine studies at the ecosystem scale have largely focused on the assessment and management of commercial fish stocks (Pikitch et al., 2004; Smith et al., 2007). In this study, however, we not only analyze the distributions and movements of prominent marine wildlife species across a large swath of the Mid-Atlantic coastal region, but also examine the influence of biotic and abiotic factors, such as productivity, depth, and salinity, on these distributions and movements. This ecosystem-based approach also establishes a broad baseline from which we may be able to detect and understand the impacts of future activities in this ecologically and economically important region.

The Mid-Atlantic and Maryland study areas

Politically, the coastal Mid-Atlantic region includes the states of Virginia, Maryland, Delaware, New Jersey, and New York. Oceanographically, however, the waters off the East Coast of the U.S. are divided into three large geographic zones (the Gulf of Maine/Bay of Fundy, the Mid-Atlantic Bight, and the South Atlantic Bight). The central sector, the Mid-Atlantic Bight, spans an area from Cape Cod south to Cape Hatteras. This central region of the Outer Continental Shelf is characterized by a broad expanse of gently-sloping, sandy-bottomed continental shelf that extends up to 150 km to the shelf edge, where the waters reach about 200 m deep. On the seafloor, the continental shelf features a series of linear sandy ridges that run roughly parallel to shore (Field, 1980).These sand shoals provide important spawning habitat for a variety of benthic and epipelagic fishes, and support a diverse epifauna (Diaz et al., 2004). Beyond the shelf edge, the continental slope descends rapidly to around 3,000 m. Much of the coastal region is bathed in cool Arctic waters, brought south by the Labrador Current as it travels down the east coast. At the southern end of this region, around Cape Hatteras, these cool waters collide with the warmer water of the Gulf Stream (Townsend et al., 2006). The region also exhibits a strong seasonal cycle in sea surface temperatures (spanning approximately 3-30 °C), and in salinity, with large volumes of fresh water emptying onto the shelf via the Hudson Estuary, Delaware Bay, and Chesapeake Bay.

While the marine environment of Maryland is dominated by the massive and highly productive Chesapeake Bay, Maryland also has a significant swath of oceanic waters off its eastern shore. These waters are dominated by linear shoals along the inner continental shelf, as is true in many other areas along the east coast between New York and Florida (Conkwright et al., 2000). These shallow, sandy shoals are comprised of significantly different sediments than surrounding finer, often peaty bottom sediments, and can either be attached to the shore (e.g., near barrier islands) or detached from the shoreline, as is the case for many shoals offshore of Maryland (Conkwright et al., 2000). These shoals are important resources for many species of marine wildlife (Diaz et al., 2004), but are also areas of interest for various types of offshore development, including sand mining for beach replenishment (Conkwright et al., 2000).

The Maryland Wind Energy Area (WEA), like other benthic habitats off Maryland's eastern shore, is flat and gently sloping towards the Continental Shelf, and is dominated by sandy habitats, though there are patches of fine-grained mud and gravel-cobble habitats as well, each of which support slightly different benthic faunas (Guida et al., 2015). Although most of the Mid-Atlantic Bight is soft-bottomed and devoid of major structure, patches of hard bottom exist off of Maryland and Delaware, and these natural rocky areas support substantial stands of the sea whip (*Leptogorgia virgulata*) in waters as shallow as eight meters and <16 km from shore (Packer and Dorfman, 2012). These nearshore patches of corals provide rare habitat for structure-loving fish species such as black sea bass (*Centropristis striata*) in this otherwise open, sandy region (Packer and Dorfman, 2012). Few such patches appear to be present within the Maryland WEA, however (Guida et al., 2015).

Seasonal stratification drives overall annual primary productivity across the Mid-Atlantic Outer Continental Shelf, with the largest and most persistent phytoplankton blooms in the late fall and winter (Schofield et al., 2008; Yoder et al., 2001). Areas near the mouths of Delaware Bay and Chesapeake Bay, however, typically have the highest levels of chlorophyll *a* in the Mid-Atlantic study area, due to their proximity to these highly productive estuarine ecosystems. The influxes of fresh water from the bays deliver nutrients such as nitrogen and phosphorus, and year-round mixing of saline and fresh waters through estuarine circulation, in combination with strong tidal currents, boosts primary productivity in these areas. As water flows from the bays into the coastal area, nutrient- and phytoplankton-rich waters are swept southwards by the Labrador Current into other nearshore areas. In these shallow coastal waters, sunlight is able to penetrate a relatively high proportion of the water column (Schofield et al., 2008; Xu et al., 2011), further fueling photosynthetic activity and growth of phytoplankton where nutrients are available. Downstream of Delaware Bay, the productivity in Maryland coastal waters is boosted from this infusion of nutrients.

Phytoplankton blooms are followed by a pulse in secondary productivity – zooplankton species foraging on the phytoplankton – which in turn become food for larger predators, such as small fishes. The Mid-Atlantic Bight is generally rich in these small, schooling epipelagic fishes, known as 'forage fish' due to their critical importance for many piscivorous predators, and their pivotal role in driving ecosystems worldwide (Pikitch et al., 2014). In the Mid-Atlantic region, key forage fish species include Atlantic menhaden (*Brevoortia tyrranus*), Atlantic mackerel (*Scomber scombrus*), butterfish (*Peprilus triacanthus*), sand lance (*Ammodytes americanus* and *A. dubius*), anchovies (including *Anchoa mitchelli*, *A. hepsetus*, and *Engraulis eurystole*), and 'river herring', including the alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*; Clay et al., 2014; Kenney et al., 1997; Safina et al., 1990). Two large invertebrate species, the longfin inshore squid (*Loligo paeleii*) and the northern shortfin squid (*Illex illecebrosus*), are also important prey items for a broad range of predators in the region (Dawe et al., 2007; Hendrickson, 2004). In Maryland, species of commercial importance off the eastern shore include Atlantic menhaden, black sea bass, bluefish (*Pomatomus saltatrix*), summer flounder (*Paralichthys dentatus*), and weakfish (*Cynoscion regalis*), among others (Vogt et al., 2015). Many of these species serve as forage fish for higher trophic level predators, such as seabirds and marine mammals, but most are also predators themselves, feeding on smaller forage species, such as anchovies, menhaden, and herring. In this study, we observed numerous schools of small fish across the region, most commonly from May to October (Chapter 11). The persistence and number of these schools was particularly notable within about 30 km of Maryland's northern shoreline (Chapter 11). The presence of these forage fish populations indicate the high levels of productivity in the area, and is likely responsible, in part, for the relatively large numbers of predators that use the area (Veit, 2015).

These relatively high levels of productivity, as compared to many other areas in the western North Atlantic (Yoder et al., 2001), ensure that the Mid-Atlantic region is used by a broad range of marine wildlife species across the entire annual cycle. The importance of the region to wildlife is also partially due to the region's central location on the eastern edge of the continent (a major migratory corridor for many species). This results in a complex ecosystem where the community composition shifts regularly, and temporal and geographic patterns are highly variable. The Mid-Atlantic supports large populations of marine wildlife in the summer, some of which breed in the area, such as coastal birds and some sea turtles. Other summer residents are visiting from the Southern Hemisphere (where they breed during the austral summer), such as shearwaters (Procellaridae) and storm-petrels (Hydrobatidae). In the fall, many of the summer residents leave the area and migrate south, but are replaced by species that breed further north and winter in the Mid-Atlantic, such as Northern Gannets (*Morus bassanus*). Many marine species also make annual migrations up and down the eastern seaboard, taking them directly through the Mid-Atlantic region in spring and fall. Many migrant terrestrial species, such as landbirds and bats, may follow the coastline on their annual trips, or choose more direct flight routes over expanses of open water. These seasonal variations in wildlife communities are explored in further detail in Chapter 2.

The Mid-Atlantic Baseline Studies and Maryland projects fill a significant information gap for wildlife in a large swath of the Mid-Atlantic region between New Jersey and North Carolina. In part, this area is a focus due to its ecological significance and relative lack of data on wildlife distributions. In addition, this region has great economic importance, including commercial fisheries, shipping, and the potential for offshore renewable energy development. The Mid-Atlantic region has a relatively high wind energy potential, with an annual average predicted offshore wind speed of 7-9 m/s (16-20 mph), and is also located near large energy markets on the U.S. Atlantic coast (Baker, 2011). Thus, the region has been a focus for offshore wind developers and regulators in recent years, and several of the first federally designated WEAs are located off the Mid-Atlantic coast. To minimize the effects of development activities on wildlife populations, however, the complexities of this ecosystem require that a range of study methods be used to obtain a comprehensive view of ecosystem structure and configuration.

In this overview of project methods, we discuss the range of study approaches used to examine the distributions, abundance, and habitat use of sea turtles, marine mammals, birds, and other wildlife. Within this report, we present survey results in a variety of ways, and a brief overview of the advantages and disadvantages of each analytical approach are also discussed.

Methods used in the Mid-Atlantic Baseline Studies Project and Maryland Project

The Mid-Atlantic Baseline Studies (MABS; 2012-2015) and Maryland (2013-2015) projects fill significant information gaps for wildlife in a large swath of the Mid-Atlantic region between New Jersey and North Carolina. The MABS project study area included waters from the state-federal boundary (5.6 km from shore) east to the 30 m isobath (roughly 40-90 km from shore) on the Outer Continental Shelf off the coasts of Delaware, Maryland, and Virginia (Figure 1-1). This study provided two years of high-density survey data and other information to improve our understanding of this ecosystem. Study methods included both boat surveys and high resolution digital video aerial surveys. The Maryland Project expanded the MABS survey effort in 2013-2014, in order to develop more detailed data on wildlife distributions, abundance, and habitat use offshore of the state. This included the extension of boat-based surveys into Maryland state waters and the expansion of high density digital video aerial surveys south and west of the Maryland WEA (Figure 1-1). This Maryland project also included a partial 15th aerial survey, conducted in August 2013. All Maryland Project survey efforts, as well as data management and quality assurance processes, were conducted in conjunction with MABS surveys, and the two datasets were combined prior to analysis.

This was the first use of digital aerial surveys on a large scale in North America, and the safety and speed with which surveys can be conducted make this approach attractive in the offshore environment. Boat-based surveys, on the other hand, provide detailed behavioral data, and the analytical approaches for boat survey data are well established. Often, approaches for studying wildlife must balance geographic vs. temporal coverage; focusing on abundance (or relative abundance) vs. obtaining detailed species identifications; and gathering data on behavior and movements vs. population-wide distributions. By using a complimentary suite of methods, we aimed to minimize knowledge gaps and develop a comprehensive understanding of the Mid-Atlantic marine ecosystem. We present results from these surveys in a variety of ways, ranging from raw observation data (for rare species such as large whales) to fully effort-corrected and bias-corrected predictive models of animal distributions and abundance. Throughout the report, data are presented for either (1) the Maryland study area (Figure 1-1), which includes Maryland Project transects as well as MABS data from transects located in federal waters offshore of Maryland, or (2) the entire MABS regional study area (including all data from both projects).

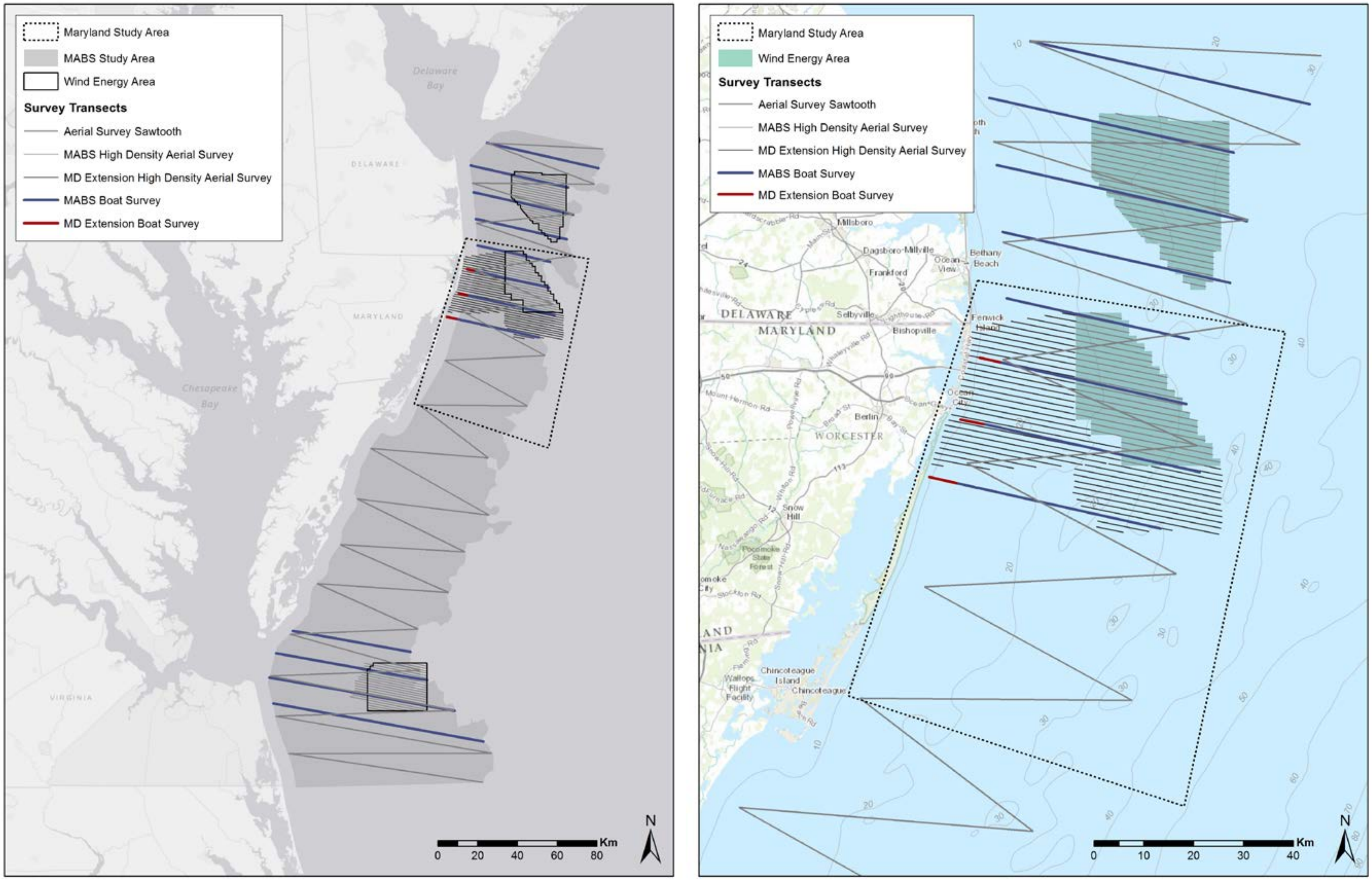

Figure 1-1. Maps of aerial and boat survey transects for the Mid-Atlantic Baseline Studies Project (left) and Maryland Project (right). High resolution digital video aerial survey transects are shown in gray (MABS) and black (Maryland); boat-based survey transects are shown in blue (MABS) and red (Maryland). The “Maryland study area” for which data are presented throughout much of this report includes data collected during both projects.

Boat surveys

Boat-based surveys are a widely-used method to monitor offshore wildlife. Due to the relatively slow speed of survey vessels, observers have time to collect data on species presence and abundance and can often record information on observed behaviors, such as an animal's interactions with conspecifics or other marine fauna (e.g., while in multi-species feeding aggregations; Chapters 6-7). Observers can also collect *in-situ* environmental and biological data, such as wind speed, wave height, sea surface temperature, salinity, and biomass densities (Chapters 6 and 8). Relating these directly to sightings can help explain the drivers of wildlife distributions, as well as variation in detection rates for different species (Ainley et al., 2005).

Detection of animals in boat surveys is not perfect, although there are methods to account for missed animals on the survey transects (Hedley and Buckland, 2004; Royle et al., 2004; Spear et al., 2004). An observer's ability to detect or identify an animal correctly decreases with increased distance between the observer and the animal, and can be further limited by deteriorating weather conditions (Royle et al., 2004). Mammal-focused surveys have particularly strict limitations on the wave height in which accurate data can be collected (Evans and Hammond 2004). The quality of the data collected, including species identifications and distance data used for developing abundance estimates, is also dependent on the skills of the observer, which can be variable (Spear et al., 2004). When observers are unable to identify individuals to species, they are trained to record the genus or family, so as to avoid misidentification. Uncertainty in these species identifications is difficult to measure, however, and is generally under-recognized or ignored in boat-based surveys, with potential implications for abundance estimation (Conn et al., 2013; Hobbs and Waite, 2010). The simultaneous use of independent observers can provide information on observer biases (Nichols et al., 2000; Ronconi and Burger, 2009), but without any permanent record of observations, it is difficult to verify identifications on boat surveys.

The movement of the survey vessel through the environment can also alter animal behaviors, whether through disturbance or attraction (Bodey et al., 2014; Schwemmer et al., 2014; Spear et al., 2004; Williams et al., 2015). Some marine birds, such as scoters (*Melanitta* spp.), auks (Alcidae), and loons (*Gavia* spp.), will flush or dive when approached by a boat, even from several hundred meters away (Henkel et al., 2007; Schwemmer et al., 2014). Other seabirds that scavenge from fishing boats, such as Northern Gannets, are attracted to slow-moving vessels from several kilometers away (Spear et al., 2004; Votier et al., 2013). Marine mammals and sea turtles also react to the presence of vessels, with responses varying depending on the size/type of vessel, vessel speed, and the species involved (Mattson et al., 2005; Normandeau Associates Inc., 2013).

Data collected from boat-based surveys present "snapshots" at given points in time. Although boat-based surveys provide an excellent opportunity for collecting behavioral and population-level data across a broad spatial extent (e.g., seasonally), they do not easily allow for understanding of individual movements and use of the study area. Survey speed is also much lower than for aerial surveys, limiting spatial coverage. While surveying more of the study area provides greater statistical power, as more information on species distributions can be collected over a broader range of environmental features, the time required to do so leads to greater turnover of animals in the study region and results in the potential for double counting of individuals or groups as they move around the area (Spear et al., 2004). In addition, boat surveys are conducted during daylight hours in fair weather conditions, which limits our understanding of nocturnal behaviors and animal behaviors in harsher weather conditions.

High resolution digital video aerial surveys

High resolution digital video aerial surveys are a relatively new method for collecting distribution and abundance data on animals in the marine ecosystem (Thaxter and Burton, 2009). Though digital video aerial surveys have become common practice for offshore wind energy planning and monitoring in Europe (Buckland et al., 2012), this study was the first to apply these methods on a broad spatial scale in the United States. Digital aerial surveys have a high cost efficiency on broad spatial scales, and are expected to largely replace traditional visual surveys, by boat or aircraft, in the offshore environment in Europe (Buckland et al., 2012). High resolution video surveys collect information on abundance for most species and the width of the survey transect is predetermined by the camera's field of view, allowing for easy calculation of the size of the surveyed area. Given the altitude at which surveys can be flown (>600 m), there is minimal disturbance to marine wildlife, unlike with boat-based surveys (Buckland et al., 2012; Williams et al., 2015). This high altitude is considerably safer than low-level visual aerial surveys, which are flown at 60-180 m, and allows for the collection of survey data pre- and post-construction at offshore wind facilities. High resolution digital video aerial surveys also allow for the estimation of flight heights for flying animals using parallax, or the movement of animals relative to the ocean background (Chapter 5; Hatch et al., 2013), data which are sometimes used in assessments of potential collision risk for animals flying through a project site (Band, 2012). Digital aerial surveys also appear to be excellent for collecting data on aquatic animals such as marine mammals and sea turtles (Chapters 10 and 12; Normandeau Associates Inc., 2013). As with boat surveys, digital aerial surveys provide a "snapshot" of animal distributions at a given point in time, and are only flown in daylight hours under fair weather, which limits our understanding of animal behaviors at night and in harsh weather conditions.

Importantly, the data collected using digital video aerial surveys are recorded, allowing for species verifications, the application of rigorous audit protocols, and archived footage for later review (Chapters 3 and 4). This is a distinct advantage over visual survey approaches. The survey transects are relatively narrow, however, which in this study may have led to problems of availability for highly mobile animals (Williams et al., 2015). Researchers continue to develop solutions to correct for many of the detection biases described above for boat-based surveys (e.g., Sollmann et al., 2015; Chapter 9). Digital aerial surveys avoid the distance bias common to visual methods, but, to date, other forms of detection bias have not been addressed for digital aerial surveys (Williams et al., 2015).

In this study, rates of identification to species for most taxa in digital video were lower than identification rates for boat surveys (Chapter 10). Recent technological advancements in camera designs and image quality have improved identification rates beyond those seen in this study (HiDef Aerial Surveying, unpubl. data), but it is likely that some taxonomic groups may remain easier to identify from a vessel (Chapter 10). The high speed of the digital aerial survey aircraft, while beneficial for cost-effective completion of surveys in large or remote study areas, means that digital surveys provide only basic information on behavior, such as "flying" or "sitting," because the footage of each animal is brief (<1 second), and more complex behaviors can rarely be discerned. Identifications can be audited, however, and the extensive quality assurance processes afforded by the recording of video may ensure more reliable, repeatable results.

Comparing and integrating methods

By using the above survey methods to collect a broad range of data, we aimed to develop a more complete picture of the Mid-Atlantic study region. Together, boat-based and digital video aerial surveys provided relatively comprehensive information on wildlife populations in the offshore environment. Each showed distinct benefits in detecting different taxa (Figure 1-2). High resolution digital video aerial surveys provided better detection rates for aquatic animals, likely due to a combination of reduced disturbance, reduced glare, and a better field of view than is provided by either boat or visual aerial surveys, allowing for submerged animals to more easily be detected in the upper reaches of the water column (Chapters 5 and 10; Normandeau Associates Inc., 2013). Boat surveys provided better detection rates for many birds, however (Figure 1-2), which is probably due to a combination of availability bias, detection bias, and identification issues in digital video aerial surveys (Chapters 5 and 10; Williams et al., 2015). Digital aerial surveys have the advantage of being auditable and archivable, however, and include an extensive quality assurance process, which may lead to a greater degree of reliability in species identifications. The safety and speed with which digital aerial surveys can be conducted also make this approach attractive in the offshore environment, and the capabilities of digital aerial surveys will continue to improve with technological advances in the field. Boat surveys can provide detailed behavioral data, however, and had generally better rates of identification of animals to species. The analytical approaches for boat survey data are also well established.

Though each methodology has clear limitations, survey data allowed us to determine the distributions and relative abundance of taxa of interest throughout the study areas, and to develop analytical products that will be useful for marine spatial planning and decision making regarding offshore development activities. By using complementary methods, we aimed to minimize knowledge gaps and develop a more comprehensive understanding of the Mid-Atlantic marine ecosystem.

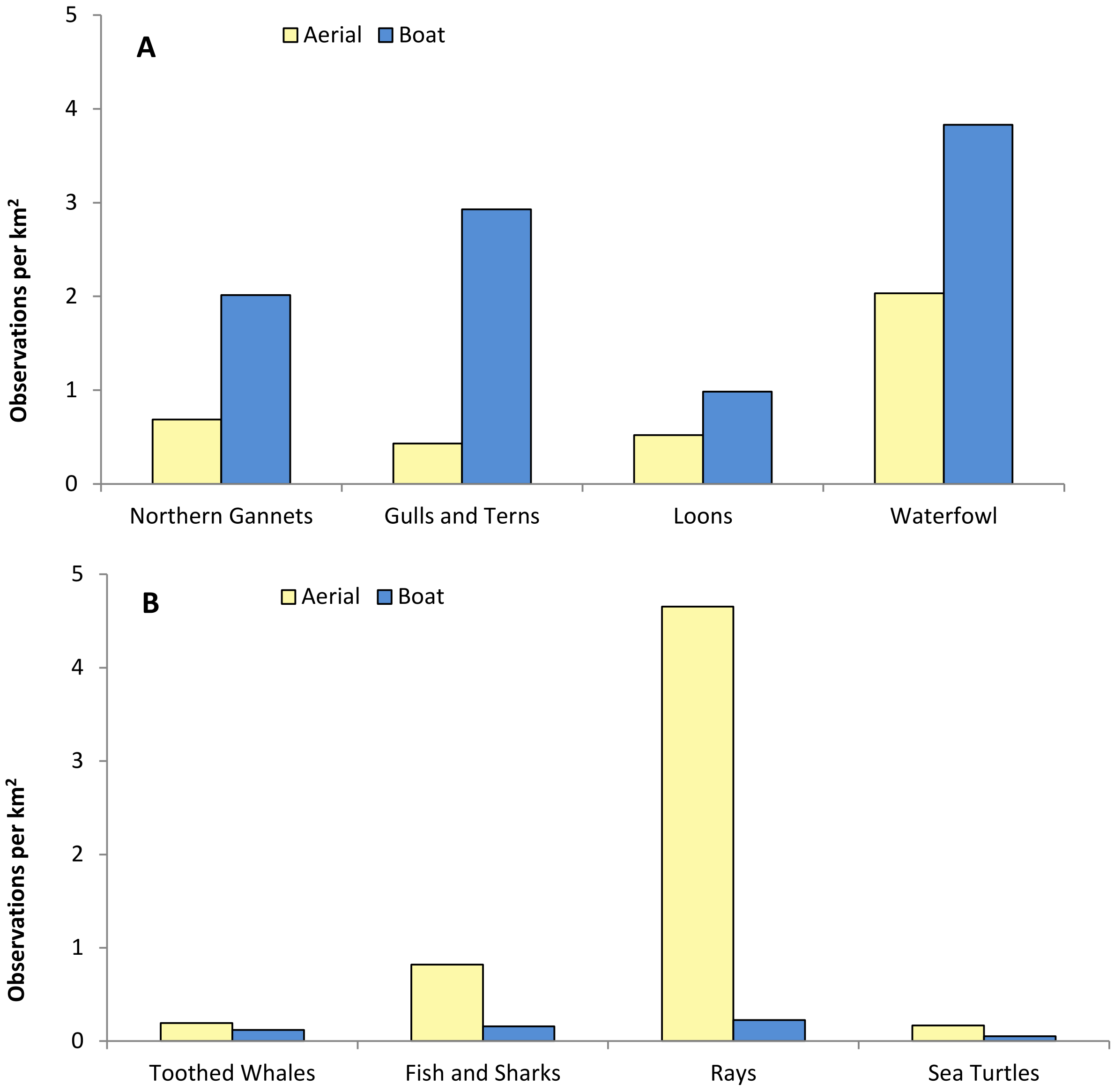

Figure 1-2. Comparison of total effort-corrected boat and aerial survey counts by taxon for all surveys (2012-2014). Aerial densities were calculated using transect strip widths (either 200 or 300m); boat densities were estimated as described below. A) Effective boat transect strip widths were estimated using distance data for each avian family (Chapter 10). B) There were insufficient data from boat surveys to develop reliable distance curves for many aquatic taxa, so estimated boat transect widths for this figure were based on the median distance of observations from the boat across all surveys (Odontoceti = 300m; Fish/Sharks = 50m; Batoidea = 7.5m; Testudines = 100m). Observations of groups that were not individually counted or identified (e.g., bait balls, ray schools) are excluded from this figure (see Chapter 4).

Interpretation and analysis of survey data

Analysis and presentation of data collected via the above study methods can take many forms. In this report, we adopted a variety of approaches for presenting spatially and temporally explicit results, and it is essential to understand their limitations in order to use resulting products appropriately. Simply mapping raw survey data, while intuitively straightforward, has several severe limitations; for example, mapping raw data precludes prediction of animal distributions, so that the only locations where estimations about animal distribution or abundance can be made are directly where surveys were conducted (Table 1-1). In addition, there are several known sources of bias associated with survey data that prevent consistency across a spatial extent (see above), making it hard to compare values between different locations without first controlling for those biases (Burnham and Anderson, 1984; Spear et al., 2004; Wintle et al., 2004).

Analysis of survey data often includes a variety of analytical corrections to account for bias and more accurately estimate how many (and which) animals are present. For example, sea state and the distance of animals from the boat transect are common factors that affect detection of animals (Chapter 9; Evans and Hammond, 2004; Hedley and Buckland, 2004; Royle et al., 2004; Spear et al., 2004; Williams et al., 2015). We would expect lower detectability of animals that are further away, especially during high sea states, so by including these two factors in a model of animal abundance, we estimated the proportion of animals that observers may have missed (Chapter 9). Survey effort is another factor that greatly influences observations made in a given location. If survey effort varies across a region (as both our boat and aerial survey efforts varied across the MABS and Maryland study areas), then areas surveyed more intensely are going to appear to support more animals. Thus, in addition to correcting for sources of bias in survey datasets, it is also important to correct for the amount of survey effort expended in different areas in order to develop maps of distribution or abundance that show real biological patterns (Chapter 11; Table 1-1). Biotic and abiotic factors, including weather, habitat characteristics, prey distributions, hydrography, drive the distribution and abundance of marine wildlife (Ainley et al., 2005). Environmental factors, or covariates, that we believe to be important for predicting animal distributions or abundance can be incorporated into a single modeling framework with effort and bias corrections (Chapters 9 and 12-14). This allows us to identify correlations between these covariates, and to understand the factors influencing animal distributions. These relationships can also be used to predict distributions for locations or time periods in which surveys were not conducted, given environmental covariate data at an appropriate spatial or temporal scale. Maps showing a continuous prediction surface across a large spatial scale are generally based on model predictions, rather than observed data; the data are used to determine relationships with environmental factors, and those relationships are mapped across the scale of the environmental factors.

Table 1-1. General approaches for presenting spatial data from offshore surveys. The distance between animals and the transect line, observer abilities, environmental conditions, and survey effort all can affect detection of animals, causing biases in observed data that must be corrected in order to use survey data to estimate wildlife densities or abundance.

Data Presentation	Advantages	Disadvantages	Example (map from this report)
Raw observation data	No assumptions—presents what was observed and where	Does not incorporate known sources of observer bias. Does not allow for predictions of wildlife distribution/abundance in areas that were not surveyed, or to predict future distributions in surveyed areas.	Figure 11-29 (large whales observed during boat and aerial surveys)
Bias-corrected and effort-corrected data	Uses known sources of observation bias to correct raw data and improve estimates of where animals are present, and in what numbers. Uses information about where animals were not seen during surveys in order to correct counts for variation in survey effort between locations.	Does not allow for predictions of wildlife distribution/abundance in areas or time periods that were not surveyed.	Figure 5-15 (maps of relative ray densities, corrected for effort, across areas surveyed by plane)
Model-predicted abundance or relative abundance estimates	Uses other environmental or habitat data to find correlations with effort- and bias-corrected observation data. Allows researchers to attempt to identify WHY animals are there, not just where they are. Allows for predictions of wildlife distribution/abundance in areas or time periods that were not surveyed.	Predictions include several implicit assumptions (e.g., consistency of species-habitat relationships across unsampled time/space) and require habitat data from unsampled locations that have similar levels of variation as the sampled habitat.	Figure 9-3 (predicted abundance of scoter flocks during the nonbreeding season, throughout the study area)

There are several types of modeling frameworks that can incorporate these different objectives. In this study we have focused on generalized additive models (GAMs) and generalized linear models (GLMs) using a hierarchical Bayesian framework (for a review of the use of GAMs and GLMs in ecology, see Guisan et al. 2002). Hierarchical approaches in a Bayesian framework (Chapters 9 and 13-14) can be useful for situations where distribution patterns or resource use vary with scale, and where species of interest are highly mobile and may be periodically unavailable for detection (Mordecai et al., 2011). They can provide an easily interpretable measure of uncertainty in predicted results, and allow for better fit of the model to observed data (Gardner et al., 2008; Zipkin et al., 2010). Generalized additive models (Chapter 12) are semi-parametric extensions of GLMs that use smoothing functions for predictor variables to improve model fit, and can be particularly useful for situations with highly non-linear and non-monotonic relationships between predictor and response variables (Guisan et al., 2002; Hastie and Tibshirani, 1990). This highly tailored model fit, however, can make it somewhat more difficult to interpret or generalize results to other locations or time periods (Guisan et al., 2002). Both modeling frameworks discussed in this report incorporate environmental covariates, effort corrections, and observation bias corrections into their structure for the purposes of estimating absolute abundance (as opposed to relative abundance).

Due to limitations inherent in raw data (e.g., detection bias), we generally avoided mapping raw counts, except in cases where we had insufficient data to conduct more reliable analyses (for example, with large cetaceans; Chapters 11-12). The ray distribution maps presented in Chapter 5 (Figure 5-15) are an example of effort-corrected data; all observations and survey effort were aggregated into 4.8x4.8 km lease blocks, so that we could compare the number of observations made per lease block area (regardless of how much surveying was actually conducted in each block). This correction did not include the incorporation of observation biases or environmental covariates, however, and resulting estimates of ray observations per unit area represent relative, rather than absolute, ray abundance for each lease block. Fully effort-corrected and bias-corrected predictive models, which allow for an understanding of the mechanisms driving animal distributions and the estimation of true abundance, are presented in several other chapters in this report (Chapters 9 and 13-14).

Environmental conditions are not static, and developing the capability to predict where animals will be (both in the future, and in areas that were not surveyed) based on environmental factors is essential to understanding potential changes in future distributions and abundance (Guisan and Thuiller, 2005; Zipkin et al., 2010). Due to the inherent variability in marine systems, however, it is unclear how useful descriptions of past distributions (particularly with relatively few years of data, as with this study) will be for predicting future distributions, especially over the longer term. Predictive models involve several implicit assumptions, such as consistent species-habitat relationships across unsampled time and space (Guisan et al., 2002), and it is important to understand the limitations of these and other analytical approaches so that results can be correctly interpreted.

Combining data from different sources

Regulators and resource managers are often required to make decisions about wildlife resources using imperfect information. Wildlife data are also collected in a variety of approaches and circumstances, which can make them difficult to use collectively in decision-making. As the survey data for this study were collected from both boat-based and digital video aerial platforms, there were analytical challenges involved in combining those data to develop integrated products to aid in assessing and managing wildlife resources.

Data gathered using boat and digital video aerial methods may not be directly comparable, due to differences in transect design and study area coverage, as well as the detection and availability of taxa of interest. Boat survey data require distance correction, where effective strip widths vary by taxon, making it more difficult to calculate effort data; digital video aerial data have a defined strip width and are not distance-biased, but lack a defined analytical framework for incorporating other potential sources of detection and availability bias. Each method appears to be more efficient at surveying some taxa than others (Chapter 10). We also identified several different species-habitat relationships from boat survey data than from digital aerial data (Chapter 13). As a result of this variability, our approaches for integrating datasets varied by taxon and analytical goal. In some cases (sea turtles in Chapter 12, for example), one survey dataset alone provided the best available picture of animal distributions, and combining the datasets was not effective using approaches developed to date. In other cases, we evaluated potential exposure of the marine bird community to offshore development by developing a preliminary model to integrate data from the two survey platforms, and producing a single prediction of abundance, distributions, and local hotspots (Chapter 14). Initial efforts at integrating data included the following approaches:

- Using species identifications from the boat survey to inform species proportions in the digital video aerial dataset (Hostetter et al., 2015).
- Using effort-corrected relative abundance ratios of taxa in boat vs. video aerial surveys to weight each dataset in combined maps of persistent hotspots of relative abundance (Chapter 11).
- Comparing datasets, particularly in relation to environmental covariates, to understand when and how integration is warranted (Chapter 13).
- Developing predictions of marine bird abundance and distribution that are jointly informed by aerial surveys, which encompass a large geographic area, and boat surveys, which allow for estimation of detection probability (Chapter 14).

The results of these efforts are summarized in Chapter 2 of this report, *Synthesis of Project Findings*.

Literature cited

Ainley, D.G., Spear, L.B., Tynan, C.T., Barth, J.A., Pierce, S.D., Glenn Ford, R., Cowles, T.J., 2005. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. Deep Sea Res. Part II Top. Stud. Oceanogr. 52, 123–143. doi:10.1016/j.dsr2.2004.08.016

Arkema, K.K., Abramson, S.C., Dewsbury, B.M., 2006. Marine ecosystem-based management: From characterization to implementation. Front. Ecol. Environ. 4, 525–532. doi:10.1890/1540-9295(2006)4[525:MEMFCT]2.0.CO;2

Baker, S., 2011. The Atlantic Offshore Wind Power Potential in PJM: A Regional Offshore Wind Power Resource Assessment. University of Delaware, Newark, DE, U.S.A.

Band, B., 2012. Using a Collision Risk Model to Assess Bird Collision Risks for Offshore Wind Farms. The Crown Estate Strategic Ornithological Support Services.

Bodey, T.W., Jessopp, M.J., Votier, S.C., Gerritsen, H.D., Cleasby, I.R., Hamer, K.C., Patrick, S.C., Wakefield, E.D., Bearhop, S., 2014. Seabird movement reveals the ecological footprint of fishing vessels. Curr. Biol. 24, R514–R515. doi:10.1016/j.cub.2014.04.041

Buckland, S.T., Burt, M.L., Rexstad, E.A., Mellor, M., Williams, A.E., Woodward, R., 2012. Aerial surveys of seabirds: The advent of digital methods. J. Appl. Ecol. 49, 960–967. doi:10.1111/j.1365-2664.2012.02150.x

Burnham, K.P., Anderson, D.R., 1984. The Need for Distance Data in Transect Counts. J. Wildl. Manage. 48, 1248–1254.

Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., Antonio, C.D., Francis, R., Franklin, J.F., Macmahon, J.A., Noss, R.F., Parsons, J., Peterson, C.H., Turner, M.G., Woodmansee, R.G., 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecol. Appl. 6, 665–691.

Clay, P.M., DePiper, G., Gaichas, S., Hare, J., Houde, E., Seagraves, R., 2014. Managing forage fishes in the mid-Atlantic Region, A white paper to inform the Mid-Atlantic Fishery Management Council. 40 pp.

Conkwright, R.D., Williams, C.P., Christiansen, L.B., 2000. Offshore Sand Resources in Northern Maryland Shoal Fields. Coastal and Estuarine Geology File Report No. 00-2. Department of Natural Resources, Maryland Geological Survey. Report to the Minerals Management Service, Contract # 14-35-0001-30769. 96 pp.

Conn, P.B., McClintock, B.T., Cameron, M.F., Johnson, D.S., Moreland, E.E., Boveng, P.L., 2013. Accommodating species identification errors in transect surveys. Ecology 94, 2607–2618. doi:10.1890/12-2124.1

Dawe, E.G., Hendrickson, L.C., Colbourne, E.B., Drinkwater, K.F., Showell, M.A., 2007. Ocean climate effects on the relative abundance of short-finned (Illex illecebrosus) and long-finned (Loligo pealeii) squid in the northwest Atlantic Ocean. Fish. Oceanogr. 16, 303–316. doi:10.1111/j.1365-2419.2006.00431.x

Diaz, R., Cutter, G., Hobbs, C., 2004. Potential impacts of sand mining offshore of Maryland and Delaware: Part 2-Biological considerations. J. Coast. Res. 20, 61–69.

Ehler, C., Douvere, F., 2009. Marine Spatial Planning: a step-by-step approach toward ecosystem-based management, IOC Manual and Guides No. 53, ICAM Dossier No. 6. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme, Paris: UNESCO.

Evans, P.G.H., Hammond, P.S., 2004. Monitoring cetaceans in European waters. Mamm. Rev. 34, 131–156. doi:10.1046/j.0305-1838.2003.00027.x

Field, M.E., 1980. Sand bodies on coastal plain shelves: Holocene record of the U.S. Atlantic inner shelf off Maryland. J. Sediment. Res. 50, 505–528.

Gardner, B., Sullivan, P.J., Epperly, S., Morreale, S.J., 2008. Hierarchical modeling of bycatch rates of sea turtles in the western North Atlantic. Endanger. Species Res. 5, 279–289. doi:10.3354/esr00105

Griffies, S.M., 2004. Fundamentals of ocean climate models. Princeton University Press, Princeton, NJ.

Grumbine, R.E., 1994. What Is Ecosystem Management? Conserv. Biol. 8, 27–38. doi:10.1046/j.1523-1739.1994.08010027.x

Guida, V., Drohan, A., Johnson, D., Pessutti, J., Fromm, S., Mchenry, J., Gallager, S., Stokesbury, K., Drucker, J.R., Burns, K., Bethoney, N., 2015. January 2015 NOAA / NEFSC / MD Interim Report Report on Benthic Habitats in the Maryland Wind. Rep. to U.S. Dep. Inter. Bur. Ocean Energy Manag. under Interag. Agreem. M13PG00019/02 86.

Guisan, A., Edwards Jr, T.C., Hastie, T., 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecol. Modell. 157, 89–100.

Guisan, A., Thuiller, W., 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. 8, 993–1009. doi:10.1111/j.1461-0248.2005.00792.x

Hastie, T.J., Tibshirani, R., 1990. Generalized additive models. Stat. Sci. 1, 297–318. doi:10.1016/j.csda.2010.05.004

Hatch, S.K., Connelly, E.E., Divoll, T.J., Stenhouse, I.J., Williams, K.A., 2013. Offshore observations of eastern red bats (Lasiurus borealis) in the mid-Atlantic United States using multiple survey methods. PLoS One 8, 1–8. doi:10.1371/journal.pone.0083803

Hedley, S.L., Buckland, S.T., 2004. Spatial models for line transect sampling. J. Agric. Biol. Environ. Stat. 9, 181–199. doi:10.1198/1085711043578

Hendrickson, L.C., 2004. Population biology of northern shortfin squid (Illex illecebrosus) in the Northwest Atlantic Ocean and initial documentation of a spawning area. ICES J. Mar. Sci. 61, 252–266. doi:10.1016/j.icesjms.2003.10.010

Henkel, L.A., Ford, R.G., Tyler, W.B., Davis, J.N., 2007. Comparison of Aerial and Boat-based Survey Methods for Marbled Murrelets Brachyramphus Marmoratus and Other Marine Birds. Mar. Ornithol. 35, 145–151.

Hobbs, R.C., Waite, J.M., 2010. Abundance of harbor porpoise (Phocoena phocoena) in three Alaskan regions, corrected for observer errors due to perception bias and species misidentification, and corrected for animals submerged from view. Fish. Bull. 108, 251–267.

Hostetter, N., Gardner, B., Gilbert, A., Connelly, E., Duron, M., 2015. Modeling species assignment in strip transect surveys with uncertain species identification, Wildlife Densities and Habitat Use Across Temporal and Spatial Scales on the Mid-Atlantic Outer Continental Shelf: Final Report to the Department of Energy EERE Wind & Water Power Technologies Office, Award Number: DE-EE0005362. BRI ID# 2015-11. Biodiversity Research Institute, Portland, ME.

Kenney, R.D., Scott, G.P., Thompson, T.J., Winn, H.E., 1997. Estimates of prey consumption and trophic impacts of cetaceans in the USA northeast continental shelf ecosystem. J. Northwest Atl. Fish. Sci. 22, 155–171. doi:10.2960/J.v22.a13

Leslie, H.M., McLeod, K.L., 2011. Confronting the challenges of implementing marine ecosystem-based management. Front. Ecol. Environ. 5, 540–548. doi:10.1890/060093

Mattson, M.C., Thomas, J.A., St. Aubin, D., 2005. Effects of Boat Activity on the Behavior of Bottlenose Dolphins (Tursiops truncatus) in Waters Surrounding Hilton Head Island, South Carolina. Aquat. Mamm. 31, 133–140. doi:10.1578/AM.31.1.2005.133

Mordecai, R.S., Mattsson, B.J., Tzilkowski, C.J., Cooper, R.J., 2011. Addressing challenges when studying mobile or episodic species: hierarchical Bayes estimation of occupancy and use. J. Appl. Ecol. 48, 56–66. doi:10.1111/j.1365-2664.2010.01921.x

Nichols, J., Hines, J.E., Sauer, J.R., Fallon, F.W., Fallon, J.E., Heglund, P.J., 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117, 393–408.

Normandeau Associates Inc., 2013. High-resolution Aerial Imaging Surveys of Marine Birds, Mammals, and Turtles on the US Atlantic Outer Continental Shelf—Utility Assessment, Methodology Recommendations, and Implementation Tools, Report prepared under BOEM Contract #M10PC00099. U.S. Department of the Interior, Bureau of Ocean Energy Management Headquarters, Herndon, VA.

Packer, D., Dorfman, D., 2012. Chapter 5: Deep Sea Corals, in: A Biogeographic Assessment of Seabirds, Deep Sea Corals and Ocean Habitats of the New York Bight: Science to Support Offshore Spatial Planning. NOAA Technical Memorandum NOS NCCOS 141. Silver Spring, Maryland, pp. 69–85.

Pikitch, E.K., Rountos, K.J., Essington, T.E., Santora, C., Pauly, D., Watson, R., Sumaila, U.R., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Heppell, S.S., Houde, E.D., Mangel, M., Plagányi, É., Sainsbury, K., Steneck, R.S., Geers, T.M., Gownaris, N., Munch, S.B., 2014. The global contribution of forage fish to marine fisheries and ecosystems. Fish Fish. 15, 43–64. doi:10.1111/faf.12004

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P., Mangel, M., McAllister, M., Pope, J., Sainsbury, K., 2004. Ecosystem-based Fishery Management. Science (80-.). 305, 346–347.

Ronconi, R.A., Burger, A.E., 2009. Estimating seabird densities from vessel transects: distance sampling and implications for strip transects. Aquat. Biol. 4, 297–309.

Royle, J.A., Dawson, D.K., Bates, S., 2004. Modeling Abundance Effects in Distance Sampling. Ecology 85, 1591–1597.

Ruckelshaus, M., Klinger, T., Knowlton, N., DeMaster, D.P., 2008. Marine Ecosystem-based Management in Practice: Scientific and Governance Challenges. Bioscience 58, 53. doi:10.1641/B580110

Safina, C., Wagner, R.H., Witting, D.A., Smith, K.J., 1990. Prey delivered to Roseate and Common Tern chicks; composition and temporal variability. J. F. Ornithol. 61, 331–338.

Schofield, O., Chant, R., Cahill, B., Castelao, R., Gong, D., Kahl, A., Kohut, J., Montes-Hugo, M., Ramadurai, R., Ramey, P., Yi, X., Glenn, S., 2008. The Decadal View of the Mid-Atlantic Bight from the COOLroom: Is Our Coastal System Changing? Oceanography 21, 108–117.

Schwemmer, P., Mendel, B., Sonntag, N., Dierschke, V., Garthe, S., 2014. Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. Ecol. Appl. 21, 1851–1860.

Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C., Shoulder, P., 2007. Scientific tools to support practical implementation of ecosystem based fisheries management. ICES J. Mar. Sci. 64, 633–639.

Sollmann, R., Gardner, B., Gilbert, A., Williams, K., Veit, R., 2015. A community distance sampling model to investigate the abundance and distribution of seabirds, Wildlife Densities and Habitat Use Across Temporal and Spatial Scales on the Mid-Atlantic Outer Continental Shelf: Final Report to the Department of Energy EERE Wind & Water Power Technologies Office, Award Number: DE-EE0005362. BRI ID# 2015-11. Biodiversity Research Institute, Portland, ME.

Spear, L.B., Ainley, D.G., Hardesty, B.D., Howell, S.N.G., Webb, S.W., 2004. Reducing biases affecting at-sea surveys of seabirds: Use of multiple observer teams. Mar. Ornithol. 32, 147–157.

Tallis, H., Levin, P.S., Ruckelshaus, M., Lester, S.E., McLeod, K.L., Fluharty, D.L., Halpern, B.S., 2010. The many faces of ecosystem-based management: Making the process work today in real places. Mar. Policy 34, 340–348. doi:10.1016/j.marpol.2009.08.003

Thaxter, C.B., Burton, N.H.K., 2009. High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols, Report commissioned by COWRIE Ltd.

Townsend, D.W., Thomas, A.C., Mayer, L.M., Thomas, M.A., Quinlan, J.A., 2006. Oceanography of the Northwest Atlantic Continental Shelf, in: Robinson, A.R., Brink, K.H. (Eds.), The Sea, Vol. 14A. Harvard University Press, Cambridge, pp. 119–168.

Veit, R., 2015. Spatial association between seabirds and prey on the mid-Atlantic Outer Continental Shelf, Wildlife Densities and Habitat Use Across Temporal and Spatial Scales on the Mid-Atlantic Outer Continental Shelf: Final Report to the Department of Energy EERE Wind & Water Power Technologies Office, Award Number: DE-EE0005362. BRI ID# 2015-11. Biodiversity Research Institute, Portland, ME.

Vogt, B., Franke, E., Cummins, J., Fabrizio, M., Frye, J., Gary, M., Grist, J., Havens, K., Holzer, J., Ihde, T., King, B., Lukens, R., Ogburn, M., Poukish, C., Price, J., Smith, G., Tango, P., Uphoff, J., 2015. Forage Fish Outcome: Management Strategy (Draft for public review, March 16, 2015), Chesapeake Bay Management Strategy: Forage Fish. Chesapeake Bay Program. Annapolis, Maryland.

Votier, S.C., Bicknell, A., Cox, S.L., Scales, K.L., Patrick, S.C., 2013. A Bird's Eye View of Discard Reforms: Bird-Borne Cameras Reveal Seabird/Fishery Interactions. PLoS One 8. doi:10.1371/journal.pone.0057376

Wiebe, P.H., Harris, R.P., Werner, F.E., Young, B. De, 2009. BASIN: Basin-scale Analysis, Synthesis, and Integration. Science Plan and Implementation Strategy, GLOBEC Report 27. Plymouth, UK.

Williams, K., Stenhouse, I., Adams, E., Connelly, E., Gilbert, A., Duron, M., 2015. Integrating novel and historical survey methods: a comparison of standardized boat-based and digital video aerial surveys for marine wildlife in the United States, Wildlife Densities and Habitat Use Across Temporal and Spatial Scales on the Mid-Atlantic Outer Continental Shelf: Final Report to the Department of Energy EERE Wind & Water Power Technologies Office, Award Number: DE-EE0005362. BRI ID# 2015-11. Biodiversity Research Institute, Portland, ME.

Wintle, B.A., McCarthy, M.A., Parris, K.M., Burgman, M.A., 2004. Precision and bias of methods for estimating point survey detection probabilities. Ecol. Appl. 14, 703–712. doi:10.1890/02-5166

Xu, Y., Chant, R., Gong, D., Castelao, R., Glenn, S., Schofield, O., 2011. Seasonal variability of chlorophyll a in the Mid-Atlantic Bight. Cont. Shelf Res. 31, 1640–1650. doi:10.1016/j.csr.2011.05.019

Yoder, J.A., O'Reilly, J.E., Barnard, A.H., Moore, T.S., Ruhsam, C.M., 2001. Variability in coastal zone color scanner (CZCS) Chlorophyll imagery of ocean margin waters off the US East Coast. Cont. Shelf Res. 21, 1191–1218. doi:10.1016/S0278-4343(01)00009-7

Zipkin, E.F., Gardner, B., Gilbert, A.T., O'Connell, A.F., Royle, J.A., Silverman, E.D., 2010. Distribution patterns of wintering sea ducks in relation to the North Atlantic Oscillation and local environmental characteristics. Oecologia 163, 893–902.