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Determining Fine-scale Use and Movement Patterns of Diving Bird Species in Federal Waters of the Mid-Atlantic United States Using Satellite Telemetry

US Department of the Interior
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ABOUT THE COVER

Cover photos (clockwise from top left, Northern Gannet, Red-throated Loon, and Surf Scoter tagged with Platform Terminal Transmitters) courtesy of Jonathan Fiely (USGS). Used with permission.

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Summary

Offshore wind energy development in the United States is projected to expand in the upcoming decades to meet growing energy demands and reduce fossil fuel emissions. There is particular interest in commercial offshore wind development within Federal waters (i.e., > 3 nautical miles from shore) of the mid-Atlantic. In order to understand the potential for adverse effects on marine birds in this area, information on distribution and behavior (e.g., flight pathways, timing, etc.) is required for a broad suite of species. In areas where offshore wind development is likely to occur, such information can be used to identify high use areas during critical life stages, which can inform the siting of offshore facilities. It can also be used to provide baseline data for understanding broad changes in distributions that occur after offshore wind developments are constructed in a specific area.

The primary objective of this study was to determine fine scale use and movement patterns of three species of diving marine birds, Red-throated Loon (*Gavia stellata*), Surf Scoter (*Melanitta perspicillata*), and Northern Gannet (*Morus bassanus*), in Federal waters of the mid-Atlantic U.S. during migration and winter. These species are each found in relatively large numbers and represent a cross-section of marine birds within mid-Atlantic U.S. waters during this time period. They are all considered species of conservation concern, and also exhibit traits that may make them vulnerable to the adverse effects of offshore wind development.

Additional objectives included: 1) linking areas used by each species across seasons (e.g., delineating source breeding populations); 2) designing and testing externally mounted transmitter attachment techniques, and assessing improved tracking technology on focal species, with goals of increased tag longevity, reduced bird mortality, and a more continuous record of movement pathways; and 3) developing winter capture techniques for Northern Gannets, which had not previously been targeted for at-sea capture during winter. This study also examined practices during tag attachment that could cause capture stress, and post-tagging mortality, in an effort to reduce such impacts.

In order to determine use and movement patterns of our three study species, we tagged 239 adult birds, primarily in bays and near-shore waters from New Jersey to North Carolina, between 2012 and 2015, and tracked them with Platform Terminal (satellite) Transmitters (PTTs). An additional 109 Surf Scoters, and 38 Northern Gannets tagged with PTTs as part of prior field efforts from other studies were also added to our analyses. Tracking data were analyzed using dynamic Brownian bridge movement models to develop spatial utilization distributions for each species. In winter, and in general, all three species exhibited a largely near-shore, coastal, or in-shore distribution within our study area (southern Long Island to the southern border of North Carolina). Habitat use was concentrated in or around large bays (e.g., Delaware, Chesapeake, Pamlico Sound), with the most extensive use at bay mouths. Northern Gannets ranged much farther offshore than the other two species, and covered a much larger area (including instances of individuals using both the Gulf of Mexico and the mid-Atlantic within a single season). Differences among species distributions were likely due to differences in motility and distribution of their preferred prey. For example, Surf Scoters, which left bays the least during winter, target largely sessile prey in shallower waters. Winter distributions of all three species were primarily inshore of current federal Wind Energy Areas (WEAs) and Lease Areas. However, WEAs and/or Lease Areas overlapped with portions of Northern Gannet distributions throughout the study area, whereas the winter home range distributions of

Surf Scoters and Red-throated Loons showed a much more limited overlap (primarily off of Massachusetts, New Jersey, and Delaware).

Resource selection analysis indicated that core use areas for all three species were associated with shallower, colder, and more productive waters, compared to other locations within each of their winter home ranges, further supporting the idea that distributions were linked to forage resources. There was variation, however, in the range of values associated with the habitat characteristics we measured within the winter core use and home range areas, which differed for each species.

All three study species used Federal offshore waters substantially more during migratory periods than in winter. Offshore use during migration was particularly extensive for Northern Gannets, with WEAs and Lease Areas overlapping their fall and spring distributions more than the other species. Red-throated Loons and Surf Scoters exhibited more coastal use than Northern Gannets during migration, and WEAs and Lease Areas generally overlapped with their distributions less extensively. The greatest overlap of WEAs and Lease Areas with Red-throated Loon and Surf Scoter distributions occurred during spring migration, and was concentrated in the northern half (MD–NJ) of our study area, and the area immediately to the north (e.g., Cape Cod and Islands), with some additional overlap of Red-throated Loon distribution further south along the North Carolina coast. Red-throated Loons and Surf Scoters often migrated overland in fall resulting in less overlap with WEAs and Lease Areas during this period. Despite the increased use of Federal waters and consequent increased potential for exposure to future offshore wind development in WEAs and Lease Areas during migratory periods, the overall area of overlap and potential exposure generally made up a very small percentage of the overall distributions of our study species during this period (< 5%), and occurred during a brief portion of the annual cycle.

Fall migration was more prolonged, and less synchronized across species than spring migration. Northern Gannets were the first to arrive in the study area in fall, starting in early October, followed by Surf Scoters in mid to late October, and Red-throated Loons in mid-November. All three species began to depart the study area by mid-April and the vast majority of individuals had departed the study area by mid-May. Differences in average dates of arrival and departure in the study area between males and females were noted for Red-throated Loons and Northern Gannets, with females generally arriving earlier and departing later. No such difference was noted for Surf Scoters.

Most of our deployed satellite tags transmitted long enough to identify the wintering area and breeding area for each individual, establishing a connection between birds wintering in the mid-Atlantic, and their source populations. Locations of and distances to breeding areas varied widely among the three species. Red-throated Loons had the longest migration and most dispersed breeding distribution, with breeding birds spread across the Arctic and Subarctic from the Northwest Territories to northwest Greenland. Surf Scoters also widely dispersed to breeding grounds, primarily in middle and eastern portions of Subarctic Canada. Tagged Northern Gannets associated with five of the six North American breeding colonies, all of which occur in Atlantic Canada. Most of the tagged Northern Gannets associated with Bonaventure Island, which supports by far the largest breeding colony in North America. Major stop-over sites included the Gulf of St. Lawrence for all three species, the St. Lawrence River for Red-throated Loons and Surf Scoters, Hudson Bay and James Bay and the eastern Great Lakes for Red-throated Loons, and the Northumberland Strait for Surf Scoters. A subset of 38 juvenile Northern Gannets tagged on breeding colonies in Newfoundland, dispersed much farther offshore during their fall migration than adults.

The mortality rate of all birds tagged with PTTs during our study (2012 to 2015) was slightly under 20%, with the highest rate in Red-throated Loons, and the lowest in Northern Gannets. Several medical (e.g., surgeon experience, distance between capture and deployment sites, use of midazolam, presence of captivity-related injuries) and non-medical factors (e.g., weather during and immediately after release; bird age, sex, and mass; sea surface temperature) were examined to better understand how the surgical implant procedure may have affected their survival. Surprisingly, few of these factors were found to be correlated with survival. In Red-throated Loons, north-south wind speed and extant medical issues were significant factors affecting post release survival, while in Northern Gannets, only time under anesthesia was a significant factor. No variables examined corresponded with post-tagging survival in Surf Scoters.

In an effort to increase tag longevity, reduce bird mortality, and increase retention times over PTTs attached with existing tagging methods (surgical implants, and tail tape for some Northern Gannets), we tested novel external harness attachment methods on over 25 birds in captivity (mostly scoters) during 2013 and 2014. A newly-developed silicone harness proved the most promising and was tested on all three species in the field during 2015 and 2016 ($n = 38$). Tagged birds, however, experienced poor tag retention and notable impacts on behavior and mortality. While effectiveness varied among the species, these issues likely resulted from intolerance of the harnesses, buoyancy issues at dive depth, harness breakage during normal preening behavior, hydrodynamic drag while pursuing prey, or a combination of all of these factors. Therefore, although using silicone harnesses to attach external transmitters to marine birds shows some promise, their use remains inadvisable without further refinement of the harness design.

A new tracking technology (solar GPS-GSM) was tested in 2015 and 2016, in conjunction with the experimental silicone harness techniques. In addition, 10 GPS-GSM tags were attached to Northern Gannets using a tail tape attachment (limited tag retention of 2-4 months) in 2016. GPS-GSM tags provided location data at a greater precision and frequency than PTT tags. Although finding an ideal external attachment method is still an issue with these tags, we present a pilot analysis of migration data showing how GPS-GSM technology may be used in future studies to provide a more complete understanding of fine-scale movement patterns of marine birds.

Overall, this study tracked movements of over 400 individuals of three species over the course of five years; one of the most comprehensive satellite tracking studies of marine birds ever conducted in Atlantic North America. Results provide a better understanding of how diving birds use offshore areas of the mid-Atlantic U.S. and beyond, and, in combination with results from other types of research (e.g., surveys, other tracking work), can be used to inform placement and pre- and post-construction impact assessments of offshore energy infrastructure. Additional work is needed to put the extensive quantity of information collected on birds in the offshore environment into a common analytical framework for undertaking the most informed management decisions (see Chapter 7).

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Abbreviations and Acronyms

AIC	Akaike Information Criterion
AMAPPS	Atlantic Marine Assessment Program for Protected Species
ANOVA	Analysis of Variance
ASY	After Second Year
ATY	After Third Year
BOEM	Bureau of Ocean Energy Management
BRI	Biodiversity Research Institute
CBC	Complete Blood Count
CO_2	Carbon Dioxide
CWS	Canadian Wildlife Service
DAF	Douglas Argos Filter
DAR	Distance, Angle and Rate
dbbmm	Dynamic Brownian Bridge Movement Models
DNA	Deoxyribonucleic Acid
DOE	US Department of Energy
DOI	US Department of the Interior
EEZ	Exclusive Economic Zone
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HMM	Hidden Markov Models
HSD	Honest Significant Difference
ICARUS	International Cooperation for Animal Research Using Space
IM	Intra Muscular
ISS	International Space Station
MAB	Mid-Atlantic Bight
MANEM	Mid-Atlantic/New England/Maritimes Waterbird Conservation Plan
mbar	millibar (unit of barometric pressure)
MBTA	Migratory Bird Treaty Act
MDAT	Marine-life Data and Analysis Team
MISE	Mean Integrated Squared Error
MODIS	Moderate Resolution Imaging Spectroradiometer
MRD	Minimum Redundant Distance
MW	Mega Watt
NARR	North American Regional Reanalysis
NCEP	National Centers for Environmental Prediction
nm	Nautical miles
NOAA	National Oceanic and Atmospheric Administration
NOGA	Northern Gannet
OCS	Outer Continental Shelf
PCBs	Persistent Organic Pollutants
PCV	Packed Cell Volume
PTT	Platform Terminal Transmitters
PCR	Polymerase Chain Reaction
PVC	Polyvinyl chloride
PWRC	Patuxent Wildlife Research Center
RSF	Resource Selection Function
RTLO	Red-throated Loon
SD	Standard Deviation

SDJV	Sea Duck Joint Venture
SDM	Species Distribution Models
SED	Sediment
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SUSC	Surf Scoter
UD	Utilization Distribution
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
UV	Ultra Violet
VHF	Very High frequency
VIF	Variance Inflation Factors
WEA	Wind Energy Area

1. Introduction

Wind power is increasingly recognized as an accessible, carbon-emission-free energy source that can help meet growing energy requirements while mitigating the environmental impacts of fossil fuel-based energy generation (Allison et al. 2008, Snyder and Kaiser 2009, Bruckner et al. 2014). In Europe, offshore wind production has grown faster than almost any other renewable energy resource, with 12,000+ MW of generation capacity produced as of the end of 2016 (WindEurope 2017). While few offshore turbines have been constructed in the United States (U.S.) to date, there is extensive energy potential in U.S. waters and a growing interest in developing it (U.S. DOE and U.S. DOI 2016). This is particularly true off the Atlantic coast, where the first major offshore wind facility became operational in Rhode Island state waters in late 2016 (Deepwater Wind 2017).

The rapid development of large-scale offshore wind facilities in Europe and increasing interest in offshore wind development in the U.S. has led to concerns over potential adverse effects on wildlife that use the marine environment (Drewitt and Langston 2006, Snyder and Kaiser 2009, Goodale and Milman 2014). For birds, potential adverse effects include turbine collision mortality, habitat loss from avoidance of infrastructure, increased energy consumption as a result of displacement from key foraging areas and barriers to efficient flight pathways, and disturbance due to site development, including turbine construction, operation, maintenance, and deconstruction (Drewitt and Langston 2006, Fox et al. 2006, Hüppop et al. 2006, Allison et al. 2008). Vulnerability to these effects is thought to be influenced by interactions between a number of factors, including demographics and life history, population status, behavior, and other variables affecting the frequency and timing of exposure (Desholm 2009, Burger et al. 2011, Goodale and Stenhouse 2016).

Many studies have been conducted in Europe to better assess effects of offshore wind facilities on birds, particularly marine birds, which are expected to encounter them more often than other avian taxa due to their reliance on offshore environments during extended portions of their life cycles. Findings have varied greatly by location, species, and study design (Drewitt and Langston 2006, Stewart et al. 2007, Furness et al. 2013). While some marine bird species are vulnerable to collision mortality, based on factors such as flight behavior (e.g., foraging patterns, altitude, nocturnal flight) and maneuverability (Furness et al. 2013, Robinson Willmott et al. 2013), quantifying mortality rates at offshore wind facilities is exceptionally difficult, and the data required to develop robust collision risk models are often lacking (Green et al. 2016). Several studies have documented effects of wind facilities on marine bird behavior, particularly avoidance (Desholm and Kahlert 2005, Vannerman et al. 2015, Dierschke et al. 2016, Garthe et al. 2017), but the rate with which avoidance occurs has been highly variable, even for the same species in different locations, and consequences of these behavioral effects on fitness and population stability are not well understood (Stewart et al. 2007, Green et al. 2016). Therefore, the impact of offshore wind development on marine birds remains unclear, particularly in the U.S., where only five turbines been constructed in the marine environment to date (Allison et al. 2008, Deepwater Wind 2017).

Regulatory agencies in the U.S. are tasked with evaluating and mitigating threats to bird populations on public lands, under laws such as the Migratory Bird Treaty Act and the Endangered Species Act (Allison et al. 2008). This responsibility also pertains to waters within the U.S. Atlantic Outer Continental Shelf (OCS), where several offshore wind facilities are being planned (BOEM 2017a). The Bureau of Ocean

Energy Management (BOEM) has specific jurisdiction over U.S. offshore waters beyond three nautical miles (approx. 5.6 km) of the shoreline (hereafter “Federal waters”). In order to assess potential detrimental effects to marine birds posed by wind turbines in Federal waters, information is needed on the distribution and behavior (e.g., flight pathways, timing, etc.) of a broad suite of species in areas where offshore wind development is most likely to occur. This information can be used to identify where high concentrations of birds occur during critical life stages, and better understand environmental and habitat factors that influence their distributions, allowing regulators and managers to site offshore wind developments in areas with the lowest predicted impacts (Drewitt and Langston 2006, O’Connell et al. 2009, Burger et al. 2010). Ultimately, the information can also be used to identify subsequent research and conservation priorities for species that may be most affected by offshore wind development.

During the last 10 years, several aerial- and boat-based surveys have been conducted to map distribution and abundance of marine birds in Federal waters of the U.S. Atlantic, either in response to proposed offshore wind facilities or in anticipation of future development (USFWS 2008a, NJ Department of Environmental Protection 2010, Paton et al. 2010, Williams et al. 2015, Veit et al. 2015, 2016). Survey data from these and other ongoing research efforts, such as the Atlantic Marine Assessment Program for Protected Species (AMAPPS; NOAA 2015) have recently been modelled to predict estimates of marine bird occurrence and abundance over a wide geographical area during multiple years, providing a valuable tool for considering birds in marine spatial planning (see Northeast Ocean Data Portal, http://www.northeastoceandata.org/data-explorer/?birds; Kinlan et al. 2016). While surveys may provide a “snapshot” of bird abundance and occurrence, they do not provide continuous (or even frequent) data on locations or individual movements, migratory phenology, or connectivity between wintering and breeding sites. Concentrated migratory movements occurring over brief intervals (which may vary slightly among years) may be missed. Some of these information gaps can be filled by tracking individual birds (Allison et al. 2008, Cleasby et al. 2015). Used in conjunction with surveys, individual tracking can (1) provide a more comprehensive understanding of how marine birds use offshore waters throughout the annual cycle, (2) link wintering and migratory birds to source populations (Niles et al. 2010, Cleasby et al. 2015), and (3) identify home ranges, providing critical information on ecological requirements (Seaman and Powell 1990).

Few studies have tracked individual marine birds to evaluate potential interactions with proposed offshore energy development in Federal waters of the U.S. Atlantic (*but see* Niles et al. 2010, Loring et al. 2014, SDJV 2015), and such work is largely lacking in mid-Atlantic U.S. waters (here defined as southern coast of Long Island to the southern border of North Carolina). This region is known to support substantial populations of several marine bird species during winter and migratory periods (Nisbet et al. 2013), and hosts the highest number of BOEM Lease Areas and Wind Energy Areas (WEAs) in the U.S. (BOEM 2017b). Thus, there is a pressing need to implement tracking studies for a broad suite of marine birds across the region to provide a comprehensive understanding of marine bird occurrence, movements, and timings of use, before substantial development occurs. This information can be used to identify core use areas during winter and migratory periods, including important offshore migration corridors, and ensure that offshore developments are sited away from areas with quantifiably high marine bird use (Goodale and Milman 2014). It can also be used to provide baseline data for understanding changes in marine bird distributions after offshore wind developments are constructed in the region (Allison et al. 2008).

Here we report on research conducted from 2012–2016 to track three species of diving marine birds, the Red-throated Loon (*Gavia stellata*), Surf Scoter (*Melanitta perspicillata*), and Northern Gannet (*Morus bassanus*), with satellite tags, during winter and migration, when substantial proportions of their populations use Federal waters of the mid-Atlantic U.S. (Nisbet et al. 2013). Each of these species utilizes unique habitats, and employs unique movement and foraging strategies during migration and winter (Barr et al. 2000, Mowbray 2002, Anderson et al. 2015), representing a cross-section of marine birds with varying ecological niches found throughout the region of this study and the wider North Atlantic Ocean. In addition, the Red-throated Loon and Northern Gannet are both considered to be "in most urgent need of conservation action" according to the Mid-Atlantic/New England/Maritimes Waterbird Conservation Plan (MANEM 2006) and of "highest conservation concern" to the Atlantic Marine Bird Cooperative (https://www.fws.gov/northeast/migratorybirds/marinebirdconservation.html) while the Red-throated Loon and Surf Scoter are recognized as a USFWS Northeast Birds of Conservation Concern and USFWS Birds of Management Concern, respectively (USFWS 2008b). Each species also exhibits demographic vulnerability to offshore wind development (Goodale and Stenhouse 2016) since they are long-lived, have high adult survivorship, and low reproductive output (Barr 2000, Mowbray 2002, Anderson 2015). Lastly, research in Europe has suggested that each of these species (or in the case of Surf Scoter, a closely related congener, the Common Scoter [*Melanitta nigra*]) are vulnerable to adverse effects of offshore wind development (Furness et al. 2013, Cleasby et al. 2015, Dierschke et al. 2016, Garthe et al. 2017).

The primary objective of our work was to collect and analyze tracking data to determine fine scale occurrence and movement patterns in Federal waters of the mid-Atlantic U.S. during migration and winter. Hundreds of individuals were tagged making this one of most comprehensive satellite tracking studies of marine birds ever conducted in Atlantic North America. Additional objectives included: 1) better identify connectivity and distribution of all three species across seasons (including delineating source breeding populations when possible), 2) design and test externally mounted transmitter attachment techniques on focal species, with goals of increasing tag longevity and reducing bird mortality (Fast et al. 2011, Mills et al. 2016), and 3) develop winter capture techniques for Northern Gannets, which had not previously been captured at sea on the wintering grounds.

Chapters 2–4 of this report describe satellite tracking research conducted on each of the three study species individually, and report results of our analyses of satellite tracking data for each species, including patterns of spatial use during winter and migration, timings of study area use and movements, incidences of exposure to WEAs, and habitat covariates related to use. Chapters 2–4 also report on broad migration pathways and habitat connectivity across the annual cycle of each species. Chapter 5 describes handling procedures and surgical techniques used to attach satellite tags to individuals of each species, and identifies variables that influenced mortality in tagged individuals. Chapter 6 reports on experimental work conducted in lab and field settings to test and refine external attachment methods for each species, and improve tag performance. Chapter 7 synthesizes study results, comparing and contrasting them across study species, and putting them in the context of other research. It also highlights relevant findings that can be used to evaluate the potential for interactions between wildlife and wind energy facilities within Federal waters of the U.S. Atlantic and to inform management decisions. Finally, the synthesis chapter identifies additional data gaps and pressing research needs.

2. Occurrence and Migration of Northern Gannets Wintering in Offshore Waters of the Mid-Atlantic United States

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2.1 Summary

The Northern Gannet (*Morus bassanus*) is the largest seabird that breeds in the North Atlantic Ocean. It exhibits a pelagic distribution and is emblematic of continental shelf waters on both sides of the North Atlantic. In North America, Northern Gannets breed at six colonies in eastern Canada: three in the Gulf of St. Lawrence, Québec, and three off the eastern and southern coasts of Newfoundland. During migration, Northern Gannets move widely along the eastern seaboard to wintering areas in the shelf waters of the United States – the Mid-Atlantic Bight, the South Atlantic Bight, and the northern Gulf of Mexico (Nelson 1978a, Fifield et al. 2014). In Europe, the Northern Gannet is ranked highly among waterbirds for collision risk with offshore wind turbines (Furness et al. 2013), and has also shown displacement from areas with offshore wind facilities (Johnston et al. 2014, Vanermen et al. 2015).

During the winters of 2012–2015, we captured 75 adult Northern Gannets and outfitted them with satellite transmitters to track their daily movements within the Mid-Atlantic study area (NY to NC) in winter, and their broader migratory movements throughout the remainder of the annual cycle. We also include satellite telemetry data from 38 juvenile Northern Gannets captured at two breeding colonies in eastern Canada prior to this study (2008–2010). These particular data provide a unique contrast to breeding adults as juvenile dispersal has not previously been tracked.

We determined sample population level utilization distributions by calculating individual level dynamic Brownian bridge movement model (dbbmm) surfaces. Utilization contour levels of 50 %, 75 %, and 95% were calculated and mapped for the mean utilization distribution surface.

Relative to the utilization distribution (i.e., the broader available area), adult wintering Northern Gannet core-use areas were located in shallower, more productive waters, with lower sea surface temperatures, especially areas closer to shore, and over fine sandy substrate. In general, these core use areas included Delaware Bay, Chesapeake Bay, and Pamlico Sound, though Northern Gannets also used U.S. Atlantic shelf waters widely, with a small contingent wintering in the Gulf of Mexico.

The Northern Gannet is an opportunistic forager (Montevecchi 2007) that ranges widely over much of the continental shelf and beyond, and, not surprisingly, the utilization distribution and core use areas observed in this study were large and encompassed a wide variety of habitat characteristics. Such activity increases the likelihood of exposure to offshore Wind Energy Areas (WEAs) and Lease Areas compared to other vulnerable marine bird species with more restricted or inshore foraging ranges. Construction and

operations of offshore wind energy facilities, including associated vessel traffic, could potentially cause displacement anywhere in the study area, and most likely within 30-40 km of the coast where Northern Gannets are most abundant.

2.2 Introduction

Global demand for sustainable energy sources, driven largely by the impacts of climate change, has led to the rapid development of wind energy installations in many countries. In the United States (U.S.) there is substantial interest in developing offshore wind energy generation, particularly along the eastern seaboard, adjacent to high population densities. Offshore wind energy is one of the fastest-growing segments of the global energy market, offering a clean, abundant and renewable source to meet growing energy demands (Snyder and Kaiser 2009). Yet, offshore wind facilities may have detrimental impacts on many avian species, exposing them to increased mortality through turbine collisions, altering behavior and flight pathways and disturbing and removing feeding habitat (Drewitt and Langston 2006).

The first offshore wind energy facility in the U.S. recently began operating in state waters off of Rhode Island (DeepWater Wind 2015). The Atlantic region also supports substantial natural resources, however, with unique ecological communities, including some 600,000 breeding pairs of 31 species of marine birds (Nisbet et al. 2013). Under Federal laws, regulatory agencies such as the Bureau of Ocean Energy Management (BOEM) and the U.S. Fish and Wildlife Service (USFWS) have an obligation to protect populations of marine birds in federal waters (O'Connell et al. 2009). In the eastern U.S., BOEM has specific jurisdiction over offshore waters beyond three nautical miles (approximately 5.6 km) of shore. In order to evaluate the degree of exposure of marine birds to potential detrimental effects posed by wind turbines, there is a need to collect information on the distribution and seasonal residency areas and behavior (e.g., flight pathways, seasonal use timing, etc.) of a broad suite of birds in these areas.

The Northern Gannet (*Morus bassanus*) is the largest breeding seabird in the North Atlantic Ocean. It exhibits a pelagic distribution and is emblematic of continental shelf waters on both sides of the North Atlantic. Northern Gannets are opportunistic foragers that target small to mid-sized surface-schooling fishes in dramatic plunging dives as well as diving directly from the surface (Garthe et al. 2000, Montevecchi 2007).

Northern Gannets are highly gregarious breeders, nesting in dense colonies on remote rocky islands and sea stacks. In the northwest Atlantic, they breed at six colonies in southeastern Canada: three in the Gulf of St. Lawrence, Québec, and three in the Atlantic, off the eastern and southern coasts of Newfoundland. The North American breeding population (~230,000 breeding adults; total population = ~500,000 birds, including non-breeders), which represents ~27 % of the global breeding population, has experienced a healthy rate of growth of +4.4%/annum since 1984, though this growth appears to have slowed in recent years (Chardine et al. 2013). During migration, almost the entire North American breeding population of Northern Gannets moves broadly down the southeastern Canadian and eastern U.S. coasts to winter in coastal and shelf waters, primarily in the Mid-Atlantic Bight, the South Atlantic Bight, and the northern Gulf of Mexico (Nelson 1978a, Fifield et al. 2014). A very small proportion of Newfoundland breeders are known to cross the North Atlantic to winter in the Canary Current upwelling region off of West Africa (Fifield et al. 2014), an area identified as an extremely important hotspot for pelagic fish and fisheries

(Camphuysen and van der Meer 2005) and a broad range of seabirds wintering in the eastern North Atlantic (Grecian et al. 2016).

Like many seabirds, Northern Gannets exhibit delayed maturation and a low rate of reproduction, initiating breeding around 5 years of age and laying only one egg per year (Nelson 1978a, Mowbray 2002). They are long-lived and generally exhibit high adult survival (~95 %; Chardine et al. 2013), with some birds known to survive beyond 20 years (Nelson 1978a). Members of a pair typically bond and remain together for life, and both males and females participate heavily in chick-rearing. Immature birds are known to wander widely and some may remain in the southern end of the range for the first few years of life, before returning to breeding colonies in their third or fourth year (Nelson 1978a). This particular suite of demographic characteristics make Northern Gannet populations vulnerable to increases in adult mortality (Cleasby et al. 2015), causing concern about the influence of offshore wind facilities on this population.

Owing to their relatively poor flight maneuverability and their habit of flying and plunge-diving from heights within the rotor-sweep zone of wind turbines in European waters, Northern Gannets are considered vulnerable to fatal collisions with offshore wind developments (Langston 2010, Furness et al. 2013). In Europe, the Northern Gannet ranked 5th in terms of collision risk in comparison of the flight heights of 38 marine bird species with offshore wind turbines around the U.K., the North Sea, and along the Danish and Dutch coasts (Furness et al. 2013; see also Johnston et al. 2014). A recent study of Northern Gannet movements using a combination of GPS and barometric pressure loggers suggests that conventional flight-height estimation (boat- and radar-based studies) may result in a substantial underestimate of collision risk for the species (Cleasby et al. 2015).

In addition to direct collision, Northern Gannets are also vulnerable to other recognized hazards of offshore wind development, such as avoidance/displacement, and physical habitat modification (Fox et al. 2006). Recent studies from the North Sea have shown notable avoidance of offshore wind facilities by several marine bird species (Lindeboom et al. 2011, Vanermen et al. 2015), including Northern Gannets (Dierschke et al. 2016, Garthe et al. 2017), suggesting potentially important habitat loss. Localized changes in prey populations and their distributions, as a direct result of offshore development, could also affect Northern Gannets, as has been observed in other marine bird species (Perrow et al. 2011). In the U.S., the USFWS has identified the Northern Gannet as a high priority species for Bird Conservation Region (BCR) 30, which includes most of the mid-Atlantic study area, and has specifically identified the importance of understanding their movements and distributions in relation to future offshore wind energy development (Atlantic Coast Joint Venture 2008).

Given their potential vulnerability to offshore wind development (Furness et al. 2013), the primary objectives of this study were to track the fine-scale winter movements of Northern Gannets in the Mid-Atlantic region (broadly defined), identify areas of consistent use, and describe the timing of their annual migrations in, around and through the study area, particularly within the federally-designated WEAs. Specifically, we captured adult Northern Gannets at the species' southernmost breeding colony at the Cape St. Mary's Ecological Seabird Reserve in eastern Canada during 2012 ($n = 9$) and in the mid-Atlantic offshore waters of the U.S. during the winters of 2012–2015 ($n = 66$). Northern Gannets were outfitted with satellite tags (platform terminal transmitters, PTTs). The tags were attached either externally, by taping them to the underside of the central tail feathers (a tried and tested method for this species), or internally via surgical implantation (a novel method for this species; see Chapter 5). We then tracked their daily movements through, within and around the study area in winter, and their broader seasonal migrations throughout the year.

In this report, we also draw upon satellite tagging work on juvenile Northern Gannets captured immediately after their departure from two breeding colonies in eastern Canada in 2008–2010 (*n* = 38), and equipped with tail-taped satellite tags to document the dispersal of juveniles in the Northwest Atlantic. Among seabirds, relatively little is known about the migratory patterns of immature birds, especially of juveniles during their initial dispersal from natal colonies (Alderman et al. 2010, Péron and Grémillet 2013). Yet, juvenile and immature seabirds experience the highest mortality of any age-class (Nelson 1978b), and assessments of their movements and activity at sea are important in determining factors for risk exposure, the acquisition of survival skills and recruitment success (Votier et al. 2011, Yoda et al. 2011, Riotte-Lambert and Weimerskirch 2013). We also compare the dispersal of juvenile and adult Northern Gannets from the colony at Cape St. Mary's, Newfoundland, to assess age-class differences in their fall migratory patterns, including their occurrence in the Mid-Atlantic study area. These particular data provide a unique contrast; juvenile dispersal patterns are relatively unknown and have not previously been tracked.

Overall, we describe the movements of satellite-tagged Northern Gannets, identify areas of most consistent use, and examine the relationships between satellite-derived daily locations and a suite of environmental variables, including sea surface temperature (SST) and salinity (SSS), water depth, primary productivity, and front density within their core use areas, compared to the broader available area.

2.2.1 Resource Selection

Multiple factors influence the distribution of a species during the non-breeding season, such as prey availability, habitat quality, predation pressures, and behavioral characteristics (Newton 2008). Understanding the physical and biological habitat requirements of a species throughout their annual cycle is critical for effective wildlife management. Research suggests that the quality of habitat occupied on the wintering grounds can result in carryover effects in subsequent seasons, including the timing or capacity to migrate, breeding success, or survival (Marra et al. 1998, Studds and Marra 2005). Optimal quality habitat is often indicated by the persistent annual occupancy of an area by individuals of a given species (Faaborg 2010). Spatially-explicit patterns of habitat use can be related to the distribution of resources within the seascape in order to identify the characteristics associated with high-quality habitat, which is expected to be occupied for longer periods within a season and more consistently over time in comparison to low-quality habitats (Boyce and McDonald 1999, Manly et al. 2002, Johnson 2007). Observations of animal occupancy can also be used to predict habitat use across seascapes or to understand the influence of certain habitat characteristics on a species' distribution (Long et al. 2009).

Food availability is presumably the most important factor affecting habitat use by seabirds during the nonbreeding season (Hutto 1985). Yet direct correlation with prey distributions is constrained by the hierarchical patch structure of pelagic schooling fish and crustaceans in the environment. This variation has biological significance in terms of the differential response shown by organisms to patches (Wiens

1976). Hierarchical patch structure is based on the idea that a patch at a given scale is comprised of finer-scale patches, all of which are nested within a mosaic of broader-scale patches and the responses of organisms to heterogeneity in habitat are not confined to just one level (Kotliar and Wiens 1990). Unexplained variance in the response at one scale may be due to patterns at a different scale (Hunt and Schneider 1987), and the spectrum of scales can range from the distribution patterns of populations across a species geographic range to resource selection by individuals within a home range (Wiens 1976). Subsequently, the strength of habitat associations to animal occurrence and behavior patterns are influenced by the scale of the sampling scheme. Therefore, a multi-scale approach is needed in order to understand the relative importance of local and regional factors influencing habitat selection (Boyce 2006).

Johnson (1980) identified four hierarchical scales at which animals select resources: (1) first order – the distribution of populations across the geographic range of the species; (2) second order – the home range of an individual; (3) third order – the habitats used by an individual within its home range; and (4) the individual's resources selected within each habitat. Identifying an animal's home range is an important step in resource selection studies because it presumably contains all of the individual's ecological requirements. Information bearing directly on management decisions can benefit from analyses of the effect of environmental characteristics within this area on an animal's movement behavior (Seaman and Powell 1990). The dynamic Brownian bridge model can be used to estimate a probabilistic model of home range called the utilization distribution (UD; Kranstauber et al. 2012, Worton 1989), which refers to the two-dimensional relative frequency distribution of an animal's occurrence in space and time (Van Winkle 1975). From there, the boundary of the animal's home range can be found by calculating the area that encompasses 95% of the volume of the distribution of space used (Anderson 1982; Laver and Kelly 2010). Spatial use of the landscape within an individual's home range can vary dramatically with certain *core use* areas being used more frequently than other areas, which are likely indicative of sites with reliable resources (Samuel et al. 1985).

2.3 Methods

2.3.1 Study Area

The project study area was centered on the Mid-Atlantic Bight of the U.S. Outer Continental Shelf (OCS), from the south coast of Long Island, New York, to the south coast of North Carolina (Figure 2-1). Northern Gannets were captured at three coastal sites in this region, and at two breeding sites outside this region. The results reported here are relevant to all U.S. federal waters with potential for offshore wind development on the Atlantic coast, as these birds were tracked throughout their annual ranges across the OCS, from Atlantic Canada to the Gulf of Mexico.

2.3.2 Satellite transmitters

Two satellite devices were used to track adult Northern Gannets in this study: Telonics TAV-2630 (29 g, < 1% body weight) were applied as tail-mounted devices in 2012, and IMPTAV-2640 (45 g) were implanted in birds in 2012–2014 (http://www.telonics.com/wildlife.php; Figure 2-2). Pre-surgery preparation of the implanted tags increased their weight to ~49 g (< 2 % of body weight; see Chapter 5). All field procedures, including surgical implantation of tags, were reviewed and approved under Institutional Animal Care and Use Committee number 2010-10 (USGS-PWRC). Tracking of juveniles carried out in 2008-2010 (prior to this study, but included here for comparative purposes) used two models of Sirtrack KiwiSat202 satellite tags (32 g and 38 g, both ~1 % of body weight).

2.3.3 Field Work

2.3.3.1 Winter At-sea Captures

In February–March of 2012–2015, Northern Gannets (*n* = 66; 6 in 2012, 20 in 2013, 20 in 2014, and 20 in 2015) were captured at three sites within their wintering range in the Mid-Atlantic region – Chesapeake Bay, MD and VA, Delaware Bay, DE and NJ, and Pamlico Sound, NC (Figure 2-1). Northern Gannets were captured using a night-lighting technique, whereby birds were carefully approached at night in a small boat, briefly disoriented with a powerful spotlight, and scooped from the water with a dip net. All captured birds were weighed and banded with a standard U.S. Geological Survey (USGS) metal band. Since males and females are indistinguishable in this species, a 2-4 ml blood sample was taken from the metatarsal or brachial vein for genetic sexing.

Upon capture, individuals deemed fit for transmitter implantation surgery were administered a mild sedative, then transported in adapted pet-carriers or large plastic tote containers to a veterinarian (see Chapter 5). Surgical implantations of intra-abdominal PTTs with external antenna were conducted by qualified veterinarians, based on standard surgical techniques (Korschgen et al. 1996, Mulcahy and Esler 1999, Chapter 5). Following implantation, when birds were cleared for release by the veterinarian, they were returned to the area of capture and released onto the water during daylight (Figure 2-2). Implanted satellite tags were programmed with two distinct duty cycles: 4hr ON – 13hr OFF (Feb 1–May 20 and Sept 24-Jan 31) and 2hr ON – 120hr OFF (May 21-Sept 30), designed to provide the greatest resolution of movement data during the winter months, while conserving battery power and prolonging the transmission period as much as possible.

2.3.3.2 Breeding Colony Captures

Juveniles are flightless during the first few days after colony departure, and are easily captured from small boats with dip nets during daylight hours. Thirty-eight juvenile Northern Gannets were captured in late September of 2008 (*n* = 6), 2009 (*n* = 6), and 2010, (*n* = 26) on the water immediately surrounding the colonies at Cape St. Mary's and at Funk Island Ecological Seabird Reserves, Newfoundland, during the fledging period (Figure 2-1).

In late September of 2012, adult Northern Gannets (*n* = 9) were captured on the nest at Cape St. Mary's using a telescoping noose pole. Satellite tags were attached to the undersides of tail feathers of adult and juvenile Northern Gannets using a combination of self-amalgamating tape (Tesa Tape, Inc, Charlotte, NC) and cable ties (Figure 2-2). All captured birds were weighed and banded with a standard Canadian Wildlife Service metal band on their right leg, and a ~0.5 ml blood sample was taken from the brachial vein for genetic sexing. Tail-mounted tags were expected to transmit for a few months until either the attachment failed or the tail feathers molted, and were, therefore, programmed to transmit either daily (5hr ON – 19hr OFF in 2008, 2009 and 2012) or every other day (5hr ON – 43 OFF in 2010) to maximize resolution for the limited deployment period.

2.3.4 Laboratory Work

2.3.4.1 Genetic Sexing

Northern Gannet blood samples collected at capture were sent to one of two genetic laboratories for molecular sexing. Samples collected in 2012 and 2013 were analyzed by Brettney Pilgrim at the Genomics and Proteomics Laboratory at Memorial University of Newfoundland, St. John's, NL. The sex of Northern Gannets sampled in these years was determined by polymerase chain reaction (PCR) and visualized by electrophoresis, using universal avian primers and following the methods of Fridolfsson and Ellegren (1999). In 2014 and 2015, samples were analyzed by Dr. Natalie Karouna-Renier at the Molecular Toxicology Lab of the USGS-Patuxent Wildlife Research Center, Laurel, MD. The sex of Northern Gannets sampled in these years was determined by real-time PCR following the methods of Brubaker et al. (2011), with slight modifications, and using broadly applicable avian primers (Wang and Zhang 2009).

2.3.5 Data Analyses

2.3.5.1 Satellite Telemetry – Data Processing and Analysis

Telemetry data from PTTs are collected using the Argos satellite system (http://www.argos-system.org/). A customized program written in Python programming language (Python 2.7, http://www.python.org/) was created for downloading data automatically. Argos data from this study were stored or archived at several locations including MoveBank (www.movebank.org) and servers at the USGS Patuxent Wildlife Research Center.

We compiled and analyzed archived data to remove redundant data and flag errant points using the Douglas Argos Filter (DAF, http://alaska.usgs.gov/science/biology/spatial/douglas.html). The DAF is a threshold filter that has several user-defined parameters to flag improbable locations in satellite tracking data (Douglas et al. 2012). The parameters are adjustable based on species' movement behavior and the scale of the area under observation. With the DAF, data are retained if they pass: 1) a spatial redundancy test and/or 2) a movement rate and turning angle test. Since bird data contain both short-distance, local movements and long-distance migratory events, we employed the hybrid filter of both the distance, angle and rate (DAR) and minimum redundant distance (MRD) filters. This achieved the best of both filters and in practice has produced very clean data with few erroneous points.

We compiled a database of deployment and life-history data for every PTT that was deployed, and stored the data in a shared Google spreadsheet accessible by all project investigators. The database contained information about the PTT tags themselves as well as data on the capture and deployment history of all birds. Furthermore, "life-history period" start and end dates were noted for every animal, following species-specific life-stage criteria defined by the Sea Duck Joint Venture (SDJV 2015). We identified the following life-history periods: breeding, molting, fall-staging, wintering, and spring-staging, for every year that the animal was alive and transmitted locations. We assigned final dispositions and the date of disposition for all non-active tags. We assessed sensor data for every tag to identify bird mortality (by internal body temperature sensor or mortality sensor) or battery/tag failure due to low transmitter voltage. We listed the day after last transmission as the last date of disposition for all birds with tags that stopped transmitting for either low voltage or unknown reasons. We calculated tag duration dates from the deployment start date and the final disposition date. The DAF filter works off of deployment dates to correctly parse PTT data. Since Argos-assigned PTT ID numbers can be recycled following a tag failure or mortality, it was necessary to re-run DAF filters once final dispositions were determined to allow the DAF filter to correctly parse the data. Maps presented in this report include DAF-filtered data through June 2016.

2.3.5.2 Satellite Telemetry – Data Preparation for Geospatial Analysis and Mapping

We wrote a custom script in R 3.3 (R Core Team 2016) to automate preparation of data for geospatial analysis and mapping. This script used the DAF-filtered data and the corresponding life-history period data from the deployment database to assign points to seasonal period for each individual. We included in analyses no more than a single representative year of data over no more than two years per animal per season (e.g., winter, fall migration) to avoid biasing the analyses towards individuals with more years of data. Prior studies on ducks (Mulcahy and Esler 1999, Sexson et al. 2014) indicated that behavior may be most affected by tag implant surgery during the first 14 days after the procedure, resulting in movement patterns not representative of normal behavior during this initial period. In our study, most mortalities likely resulting from implantation occurred within 30 days of surgery. In almost every case, these birds displayed movement behaviors that deviated from that of birds that did not die within 30 days, such as travel far up rivers or onto land. Therefore, we omitted birds that transmitted < 30 days after release from analyses to reduce bias from birds that could have been negatively affected by transmitter implantation and handling. Overall this made up a very small fraction of our sample. We filtered the remaining data using the DAF assigned hybrid filter to remove redundant points and those determined to have incorrect locations based on the turning angle and movement rate tests, keeping the remaining locations for analyses. We assigned mean errors (Douglas et al. 2012) to location classes (Table 1) for use in dynamic Brownian-bridge movement analyses which includes location errors in analyses (Kranstauber et al. 2012). We used the 95th error percentiles for data using the parameter MAXREDUN = 15 km in the DAF filter. While this is a liberal error assignment for locations, in practice the models are robust to changes in such values.

2.3.5.3 Brownian Bridge Movement Analysis of Winter and Migration Periods

We determined sample population level utilization distributions for each species by calculating individual level dynamic Brownian-bridge movement model (dbbmm) surfaces (Kranstauber et al. 2012) using package Move for R (Kranstauber & Smolla 2016). Most birds were captured and tagged in late winter, and PTT battery life averaged less than or equal to one year. Therefore, most tags lasted only partway through winter of the second year post-tagging. Since maximizing understanding of winter movements was a major focus of the study, we calculated separate dbbmm surfaces for each of two winters with at least five days of data and combined these into a weighted mean surface for each animal (as a percentage of the total number of days represented in the surface) with a minimum 30 total combined days of data. We removed any temporal overlap between these datasets (e.g., March 1-15 is represented only in one surface) to minimize biases introduced by overlapping temporal coverage. We used this method of combining multiple seasons for the migration periods as well, but relaxed the requirements for days of data, requiring only 5 days per year and 7 total days per period since migration duration often occurred over a much shorter time period. Utilization contour levels of 50%, 75%, and 95% were calculated for the mean utilization distribution (UD) surface. The final UD was cropped to the 95% contour for mapping and further analyses. Individual movement models were also saved for analyses of individual home range use and movement.

2.3.5.4 Use of Lease Areas and Wind Energy Areas

We calculated use of WEAs and Lease Areas by tagged Northern Gannets in two ways: 1) as a percentage of overlap of each WEA and Lease Area by the 50% (*core use*) and 95% (*home range*) UD areas, and 2) as a percentage of the total 50% (core use) and 95% (home range) UD seasonal distributions area overlapped by the WEA and/or Lease Area. Spatial overlap was determined in R version 3.3.1 (R Core Team 2016) using package raster (Hijmans 2016). Low sample sizes limited our analysis to the aggregate distribution of individuals across all years of the study and available data. Overlap of Lease Areas and/or WEAs and the seasonal distribution of our sample represented a probability (Kie et al 2010) that individuals used the areas during the season, and would have been exposed if turbines were present in those areas, and the % of the entire area that individuals used that was occupied by a WEA and/or Lease Area.

2.3.5.5 Point Generation for Resource Selection Models

We used a custom script in R version 3.3 (R Core Team 2016) to generate two random points in the home range of each animal for every core use location. The dates for each matched core-use point were used for assigning temporally-explicit covariates (e.g., SST, chlorophyll *a*) to the random points.

2.3.5.6 Arrival and Departure into and out of the Study Area by Sex

We plotted the latitudes of all tagged individuals by date to show latitudinal progression from wintering grounds to breeding grounds, and back. We separated plots by sex, aggregated data into 5-day intervals and calculated mean (± standard deviation) latitudes for each interval. We further split data by colony of origin and colony regions (Gulf of St. Lawrence and Newfoundland) to highlight colony and/or regional differences in movement patterns.

We generated histograms of the proportion of all animals with active tags south of the northernmost boundary of the BOEM study area (41^{o} N latitude), and north of the southern boundary (33.5^{o} N). We used proportion instead of raw counts because the number of active tags was not consistent over the year and resulted in graphs biased by the number of active tags in the study area. We determined the date of first arrival in fall south of the northern boundary and the last departure in spring north of the study area. We generated histograms for combined and separate sexes.

2.3.5.7 Habitat Selection

We examined the resource selection of Northern Gannets to determine characteristics of preferred habitats that can be used to predict probability of use across the study area. The evaluation of resource preference pertains to the measurement of habitat components an animal *uses* in its environment compared to what is *available* during that same period (Manly et al. 2002). Johnson (1980) identified four hierarchical scales at which animals select resources. Our first objective was to identify habitat characteristics of the composite winter home range of all individuals – second order resource selection. We defined *used* as the pooled telemetry point locations that fell within the 0.95 isopleth of the dbbmm composite winter UD. Used resources are a subset of available resources, and a key factor in resource selection studies is determining the extent of the area that will be included for sampling *available* resources (Buskirk and Millspaugh 2006). We selected the Mid-Atlantic Bight as the extent of habitat available for second order resource selection of the wintering home range. The Mid-Atlantic Bight extends from Nantucket Shoals off southern New England southward to Cape Hatteras off North Carolina, and is bordered by the U.S. coastline on the west and the continental shelf-break on the east. Available points consisted of a random selection of points generated within boundaries of the Mid-Atlantic Bight that was equal to the total number of *used* points.

Our second objective was to determine the habitat characteristics of the core use areas within the composite winter home range—third-order resource selection. We used the pooled telemetry points that fell within the 0.50 for the *used* or *core use* areas. Available points were generated using each individual animal's UD, and, for each core use point within the 0.50 isopleth, two random points were generated within the animal's 0.95 isopleth. Matching points as such allowed us to assign certain data associated with the core use point to the random points, including animal ID, sex, date, and time. Considerations of juvenile movements and areas of occupation are presented later. The selection of telemetry point locations within the 0.50 isopleth for comparison of the habitat characteristics of those points to points generated within the individual's 0.95 utilization distribution is described in greater detail under sampling protocol-A in Manly et al. (2002).

Habitat characteristics were chosen based on *a priori* knowledge of marine habitat and availability of spatial data within the study area, and included water depth (m), distance to shore (km), long-term (10-yr winter mean) and monthly mean sea surface temperature (SST; °C), monthly mean chlorophyll *a* (mg/m^3), long-term (6-yr winter mean) and monthly mean sea surface salinity (SSS; practical salinity units, psu), and sediment grain size (mm). We measured water depth using the NOAA National Geophysical Data Center 3 arc-second Coastal Relief Model for the United States (NOAA 2014a). To estimate distance from shore, we calculated the Euclidean distance between Northern Gannet locations and the nearest segment of the NOAA Medium Resolution Digital Vector Shoreline (1:70,000) using the Near Tool in Arcmap 10.2.2 (ESRI, Redlands, CA; NOAA 2014b). Sediment grain size categories were also obtained from the Nature Conservancy's Northwest Atlantic Marine Ecoregional Assessment data portal. Size categories were grouped by the Nature Conservancy according to correlations with benthic habitat communities, and are not necessarily related to Northern Gannet habitat requirements. For the dynamic variables with a temporal component, we used Marine Geospatial Ecology Tools to retrieve values for each location based on the date of transmission (Roberts et al. 2010). To measure ocean productivity, we obtained monthly estimates of chlorophyll *a* concentration (mg/m^3) produced by the NASA Goddard Space Flight Center's Ocean Data Processing System. These data had a spatial resolution of 4 km and were derived from radiometric measurements of chlorophyll fluorescence made by the Aqua sensor aboard the MODIS satellite system (Mueller et al. 2003). Raster and polygon data layers of previously described habitat measurements and animal location data layers were analyzed in ArcGIS 10.2.2. using the WGS 84 spatial projection.

We used the R package, *lme4*, to create generalized linear mixed models, in which animal ID was included as a random effect to allow the intercept to differ among individuals to model habitat covariate effects on used versus available locations with the *lme4* package in R (Bates et al. 2015, R Core Team 2016). Model development was exploratory, but, based on *a priori* knowledge of seabird habitat, we predicted that used locations would be related to nine habitat covariates: depth, distance to shore, long-term and monthly chlorophyll *a*, long-term and monthly SST, long-term and monthly SSS, and sediment grain size. Point locations from the winter dbbmm analysis were included in the resource selection models only if complete coverage was available for all the measured habitat characteristics described above. Culling point locations with incomplete coverage, however, generally resulted in the inclusion of fewer individuals in the resource selection analyses (n = 31) than the number included in the winter dbbmm analyses (n = 34). This approach ensured consistency among data sets during the model selection process (described below) for each of the resource selection analysis efforts. Correlations between pairs of continuous habitat variables were quantified using a Pearson product-moment correlation matrix. Multicollinearity among covariates was assessed by calculating variance inflation factors (VIF; Zuur et al. 2009). Covariates with pairwise correlations of < 0.60 and VIF values of < 2.3 were retained as variables in the modeling process. Correlation and VIF results indicated multicollinearity among the following variables: (1) long-term and monthly SST, (2) long-term to monthly SSS, and (3) long-term to monthly chlorophyll *a* concentration.

Data were fitted to each singular term to determine the covariate best suited for including in the suite of candidate resource selection models. Results indicated that long-term mean winter SST, SSS, and chlorophyll *a* were stronger predictors of use for Northern Gannets compared to mean monthly SST, SSS, and chlorophyll *a*. Correlation and VIF values of the remaining variables were all within the above stated limits.

We used a nested model approach and candidate models were ranked with Akaike Information Criterion (AIC). The model with the lowest AIC, and those having $\Delta\text{AIC} \leq 2$ had the most statistical support, values between 4 and 7 had considerably less support, and those > 10 had virtually no support (Burnham and Anderson 2002). The Akaike weight was also considered when determining the relative statistical support for each model. The importance of the individual explanatory variables in the top nested model were assessed by dropping one term in turn and further comparing AIC values to determine if any variables could be dropped from the model. We estimated confidence intervals for the best-fit population-level resource selection function (RSF) model using model-based semiparametric bootstrapping (n = 1,000 iterations) calculated from the *bootMer* function within the *lme4* package.

We used JMP 9.0 to conduct nonparametric Wilcoxon rank sums tests to examine differences in habitat characteristics between male and female Northern Gannet core use areas and home ranges (JMP, Version 9). All tests were considered significant at $P < 0.05$.

2.3.5.8 Juvenile Data

All classes of Argos locations were retained and an iterative McConnell speed filter was applied to discard unrealistic locations that required sustained speeds of ≥ 84 km h^{-1} (Garthe et al. 2007), executed in package 'trip' written in Cran-R (Sumner 2006, www.r-project.org). Of the total 12,821 locations collected between 2008 and 2010, 97.4% were retained after the speed filter application (n = 12,482). All filtered locations were imported into ArcMap (ver. 10), and mean daily centroids were calculated for all individuals using the Spatial Statistics tool and associated bathymetric data were extracted from ETOPO2 grids (www.ngdc.noaa.gov/mgg/global/etopo2.html) using the Spatial Analyst tool. Alternating daily centroid values were excluded for birds in 2008 and 2009 to generate comparable estimates of movement patterns with 2010 birds that were programmed at a lower resolution (2-day versus 1-day duty cycle). For all data from 2008-2010, analyses of daily movement patterns of juvenile Northern Gannets from their natal colonies was limited to individuals with > 7 unique days from 1 October to 31 December, after which data were limited to only a few individuals. This resulted in the removal of 4 birds whose tags were presumably lost or failed within days after deployment, for a final sample size of 34 individuals. Individual level dbbmm surfaces (Kranstauber et al. 2012) were calculated using package Move for R (Kranstauber and Smolla 2016) and utilization contour levels of 50%, 75%, and 95 % were calculated for the mean utilization distribution (UD) surface and presented for early (1 Oct–15 Nov) and late (16 Nov–31 Dec) fall dispersal phases, each consisting of an equal 45-day period.

2.4 Results

2.4.1 Capture Summary

A total of 75 adult Northern Gannets were captured and tagged (see Appendix A). Sixty-six captured in and around Chesapeake Bay (*n* = 48), Delaware Bay (*n* = 7), and Pamlico Sound (*n* = 11; Table 2-2) were released with satellite transmitters during the winter of 2012 (*n* = 6), 2013 (*n* = 20), 2014 (*n* = 20), and 2015 (*n* = 20). Three of these individuals received transmitters using the tail-taping method, and the remaining 63 had transmitters implanted. An additional 9 breeding adults were captured at the Cape St. Mary's colony and released with satellite transmitters during fall of 2012. The overall sample included a relatively even number of males (*n* = 33) and females (*n* = 36), with the sex of only a few birds (*n* = 6) unknown. This allowed us to examine the movements and the influence of environmental factors by sex, since male and female Northern Gannets can respond differently (Fifield et al. 2014, Lewis et al. 2002). Overall, the mean body mass of wintering adults at capture was 3,384 g (± 354 g SD; range = 2,600–4,200 g; *n* = 68). The mean body mass of adult females was 3,441 g (± 325 g SD; range = 3,000–4,200 g; *n* = 35) compared with adult males at 3,336 g (± 376 g SD; range = 2,600–4,100 g; *n* = 32). Body mass measurements were unavailable for breeding adults captured in 2012.

Of the 63 birds implanted with transmitters, 11 were excluded from analysis because they did not transmit > 30 days. Based on sensor information sent from the tags on these 11 birds, 6 were known mortalities, 1 was most likely a tag failure, and 4 could not be positively assigned to either mortality or tag failure. This corresponds to potential surgery-related mortality rates of 25% (n = 5) in 2013, and 5% (n = 1) in 2014, with no known surgery-related mortalities in 2012 or 2015 (Mulcahy & Esler 1999). Satellite transmitters on birds that did not suffer mortality during the life of the transmitter had a median duration of 341 days, with a maximum duration of 570 days.

Prior to this project (and included here for comparative purposes), 38 juvenile Northern Gannets were captured at the Cape St. Mary's and Funk Island colonies. Overall, the mean body mass of juveniles was 3,767 g (± 297 g SD; range = 3,220–4,400 g; *n* = 38), and although males were slightly heavier (3,810 g ± 373 g SD; range = 3,200–4,400 g; *n* = 14) than females (3,748 g ± 239 g SD; range = 3,320–4,220 g; *n* = 22) the difference was not significant. Sex was unknown for 2 juvenile Northern Gannets.

2.4.2 Transmitter Performance

A total of 12 adult Northern Gannets were tagged using the tail-taping method: 3 of the first birds captured in Chesapeake Bay in March 2012, and the 9 birds captured in September 2012 at the Cape St. Mary's colony. The remaining 63 birds captured in this study all received surgically implanted satellite transmitters. Tail-taped tags provide limited data, as they are lost when the bird molts their tail feathers at some point over the course of the winter. In this study, tail-taped tags were retained for an average of 73 days (± 41 days SD; range = 26–176 days; n = 12). Implanted devices have the capacity to last much longer, with a potential battery life of 1+ year, depending on the duty cycle employed. Eleven (17%) of the implanted tags either did not function at all or transmitted for only a few days due to device failure or mortality. After removing these short-term tags (< 14 days) from analysis, the remaining implanted tags transmitted for an average of 303 days (± 116 days SD; range = 35–570 days; *n* = 52). Of the 38 tail-taped tags deployed on juveniles, 34 transmitted > 7 days, with an overall average deployment duration of 57 days (± 33 days SD; range = 14–143 days; *n* = 34).

2.4.3 Occurrence and Movement of Northern Gannets in Offshore U.S. Waters

2.4.3.1 Winter Use of the Study Area

Satellite-tagged Northern Gannets were present in the Mid-Atlantic study area for a considerable portion of their annual cycle – approximately 7 months, from early October to early May (Figure 2-3). Not surprisingly, based on their ability to roam widely over OCS waters, the mean winter home range (95% UD) spanned much of the OCS from the Gulf of Maine to the Gulf of Mexico. This broad winter home range included most of the Mid-Atlantic study area, with extensions offshore as far as the shelf edge in the northern half of the study area, and off of the shelf edge around Cape Hatteras, but narrowing rapidly towards shore south of this area in the South Atlantic Bight and into the Gulf of Mexico (Figure 2-4).

Within the study area, Northern Gannet locations were mostly limited to coastal waters. The area of core use (50% UD) indicated more concentrated use of coastal regions in winter, with Northern Gannets using shallower inshore waters along the coast, such as the New York/New Jersey Bight, and around large bay mouths, such as the Chesapeake Bay (Figure 2-5). Northern Gannets also showed heavy use of protected waters, such as Pamlico Sound, and well into the upper reaches of the Chesapeake Bay, including almost the entirety of the bay as far up as the Choptank River and the mouths and lower reaches of some large tributaries, including the Potomac, the Rappahannock, and the James rivers. In the Pamlico Sound area, core use areas included Cape Hatteras, the Pamlico River, and around Cape Lookout. The core use area extended south into northern Onslow Bay, with the Frying Pan Shoals at the southern end of Onslow Bay also highlighted (Figure 2-5). Beyond the study area, small disjunct areas of core use also appeared around Cape Cod, the eastern and western coasts of Florida, and off of western Louisiana in the Gulf of Mexico (Figure 2-4).

2.4.3.2 Winter Movements Within the Study Area

The first Northern Gannets arrived in the study area in early October, with females arriving a day or two before males (Figure 2-3), and birds breeding in the Gulf of St. Lawrence arriving slightly earlier than birds from Newfoundland colonies (Figure 2-6). Throughout the winter, individuals often showed clear and directed movements among core use areas within the Mid-Atlantic and beyond, with moves spanning several hundred kilometers in a matter of a few days. Overall, however, there appeared to be a slow and steady drift southward within the study area over a few months, particularly November–February (Figure 2-6), with many birds moving widely and visiting a succession of core use areas over the course of the winter. By March, Northern Gannets were beginning to work their way northward through the study area, with a concentration building up around the mouth of Chesapeake Bay reliably in mid-March before moving north through Delaware Bay and the New York/New Jersey Bight. Northern Gannets generally departed the study area in April, with a few late stragglers leaving in early May, and males departing a week before females (Figure 2-7).

Throughout the winter period, an extensive percentage of WEAs and Lease Areas overlapped with Northern Gannet home range (95% UD), including 100% overlap of all but nine WEAs and Lease Areas. Three of the additional nine WEAs and Lease Areas showed an overlapped home range by > 65% (Table 2-3). A substantially smaller percentage of WEAs and Lease Areas overlapped core use areas (50% UD), with only three showing any overlap in winter; each overlapping by < 17% (Table 2-4). The percentage of WEAs and Lease Areas overlapping with core use and home range represented only a small percentage of the total area of the core use area or home range in the study area (< 5% cumulative total; Tables 2-3 and 2-4), indicating a relatively small footprint of current WEAs and Lease Areas.

2.4.3.3 Migratory Use of the Study Area

In North America, Northern Gannets generally leave their colonies and begin moving south in late-September/early October (Mowbray 2002). In this study, the first birds arrived in the Mid-Atlantic study area in early-October, though fall migration was protracted and asynchronous, with some birds wandering south over several weeks or even months. Fall migration begins on a broad front, narrowing towards the Mid-Atlantic region with the OCS (Figure 2-8). As a result, a considerable percentage of WEAs and Lease Areas overlapped Northern Gannet home range (95% UD) during fall, particularly in northern regions (cumulative overlap = 83 %; Table 2-3). The most southerly WEAs were largely the only areas that did not overlap completely with the Northern Gannet's home range during fall migration. Most overlap with core use areas (50% UD) during fall was in New York and New Jersey. Few other WEAs overlapped with Northern Gannet core use during this period (cumulative exposure = 5 %; Table 2-4).

In early March, Northern Gannets started to move north, from the southern reaches of the study area (Figure 2-9). This led to extensive percentage of WEAs and Lease Areas overlapping Northern Gannet home range (95% UD; cumulative exposure = 59 %; Table 2-3). There was also a considerably larger percentage of WEAs and Lease Areas overlapping gannet core use areas (50% UD) during spring (cumulative exposure = 31 %) than in winter or fall (Table 2-4).

As in winter, the percentage of WEAs and Lease Areas overlapping Northern Gannet home range and core use areas during fall and spring migration, represented only a small percentage of the total area of either home range or core use area in the study area (respectively, < 5% and < 2% of cumulative total; Tables 2-3 and 2-4).

2.4.3.4 Migratory Connectivity and Breeding Areas

On departing the Mid-Atlantic study area in spring, Northern Gannets rapidly move northeast along the Atlantic coast and onto the Scotian Shelf. Beyond Cape Cod, migration takes place largely offshore on the Georges Bank in the Gulf of Maine, and the Banquereau and St. Pierre Bank on either side of the deep water Laurentian Channel (Figure 2-10) highlighted as core use areas during the fall migration. From here, Northern Gannets generally turn northwest towards the colonies of the Gulf of St. Lawrence, or head northeast towards the Newfoundland colonies. Of the birds tagged in this study, most showed some geographic association with a particular breeding colony, and, not surprisingly, most were associated with the largest breeding colony at Bonaventure Island (Table 2-5). Given that most of our satellite-tagged birds (~80%) associated with colonies in the Gulf of St. Lawrence, it should be clearly noted that our broad scale migration summary maps are biased towards the migratory behavior of birds breeding at these colonies.

On their southern migration in fall, Northern Gannets generally showed a much more coastal trajectory, with just a few individuals wandering much more widely over the OCS and outer banks, or even out over the shelf slope (Figure 2-11). Most birds closely followed the coast of Nova Scotia and the Gulf of Maine, which was highlighted as core use, with some movement across Georges Bank. South of Cape Cod, Northern Gannets stayed tight to shore down through the Mid-Atlantic Bight, and beyond.

2.4.4 Factors Influencing Occurrence

2.4.4.1 Home Range Selection

The top supported second order resource selection model predicting Northern Gannet (n = 31) selection of winter home range areas within the Mid-Atlantic Bight included long-term mean winter SST and chlorophyll *a*, distance from shore, and sediment grain size (Table 2-6). The scaled coefficients, which allow for direct comparison of the strength of the effect of covariates with different measurement units, indicated that distance from shore had the strongest effect on the selection of a winter home range; however, the coefficients for each variable were all fairly comparable in terms of effect size (Table 2-7). Mean distance from shore at Northern Gannet locations within the estimated winter home range area was 13.01 ± 13.65 km and ranged up to 121.83 km compared to available points randomly generated throughout the Mid-Atlantic Bight, which averaged 25.60 ± 23.66 and ranged up to 149.41 km (Table 2-8). Probability of winter home range selection decreased 47% with each 1 km increase in distance from shore (Table 2-7; Figure 2-12). Similarly, probability of winter home range selection decreased by 33% with each 1 °C increase in SST10 (Table 2-7; Figure 2-13). Mean SST10 within the home range was 6.54 ± 1.79 °C compared to 8.02 ± 2.84 °C at available points within the Mid-Atlantic Bight (Table 2-8). Selection of winter home range increased 23%, however, with each 1 mg/m^3 increase in CHLOR10 (Table 2-7; Figure 2-14). Indeed, CHLOR10 was 7.61 ± 5.21 mg/m^3 at Northern Gannet locations within the home range and 4.56 ± 4.34 mg/m^3 at available locations throughout the Mid-Atlantic Bight (MAB; Table 2-8). Each of the sand sediment grain size categories and gravel were associated with comparable increased probability of use relative to the silt/mud category (Table 2-7). The sand grain size of 0.17–0.35 mm, however, had the greatest frequency of occurrence at Northern Gannet locations within the winter home area (Figure 2-15).

2.4.4.2 Core Use Area Selection

Comparison of the nested models indicated that the top supported model included all covariates, though removing water depth and mean monthly SSS further reduced deviance and improved model ranking. Similar to the second order resource selection model, the final top supported third order resource selection model of Northern Gannet (n = 31) core use site selection within the winter home range included the fixed effects of long-term mean winter SST (°C) and chlorophyll *a* (mg/m^3) concentration, distance from shore (km), and sediment grain size (mm; Table 2-9). The top selected third order model also included the random effect of animal ID and a variance of 1.11 around the intercept of -1.28 was associated with each animal and an intra-class correlation among habitat characteristics found at locations of the same individual was 0.25 (Table 2-10). Probability of selection for core use areas increased 70% with each one mg/m^3 increase in CHLOR10 (Table 2-10; Figure 2-16). CHLOR10 averaged $\bar{x}$ = 7.41 ± 5.09 mg/m^3 in core use areas compared to $\bar{x}$ = 4.41 ± 4.21 mg/m^3 for the home range (Table 2-11). Core use sites were associated with colder daily SST and each 1°C increase in daily SST was associated with a 37% decrease in the probability of core use site selection (Table 2-10; Figure 2-17). SST10 in core use areas was $\bar{x}$ = 10.86 ± 3.81 °C compared to a home range mean of $\bar{x}$ = 11.91 ± 4.32 °C (Table 2-11). Core use sites ($\bar{x}$ = 13.12 ± 15.44 km) were closer to shore compared to the mean home range estimate ($\bar{x}$ = 26.67 ± 25.86 km) and each 1 km increase in distance from shore was associated with a 47% decrease in the probability of core use site selection (Tables 2-10 and 2-11; Figure 2-18). All grain sizes of sand and gravel were associated with increased probabilities of use compared to the 0.0–0.03 silt/mud grain size; however, the greatest increase was observed in the 0.17–0.35 sand category, which was associated with a 72% increase probability of use compared to the silt/mud category. Frequency of use associated with locations in the core use areas was greatest among the 0.015–0.35 sand and 0.48+ gravel categories (Figure 2-19). Wilcoxon rank sums test results indicated significant differences between males and females were observed for most environmental characteristics in both the core use areas and throughout the home range (Table 2-12). Home ranges of male Northern Gannets tended to have higher chlorophyll *a* concentrations, colder SSTs, and were nearer shore in shallower water compared to females.

2.4.4.3 Dispersal Patterns of Juvenile Northern Gannets

After initial departure from their natal colonies, satellite tagged juvenile Northern Gannets were widely dispersed over deep, offshore waters south of Newfoundland and Nova Scotia, Canada (Figure 2-20). As juveniles dispersed further south they increasingly occupied coastal areas, particularly south of Nantucket with core use areas in the US Mid-Atlantic region (Figure 2-20). One juvenile began a trans-Atlantic migration, travelling > 2400 km across the Atlantic Ocean before returning west on 30 October. During the late fall dispersal (16 Nov–31 Dec), juvenile core use areas were located in the Mid-Atlantic study area, eastern Florida, and the Gulf of Mexico (Figure 2-21). Mean water depth occupied by juvenile Northern Gannets within the Mid-Atlantic study area was 37.7 ± 32.7 m, which is deeper than areas used by adults in the Mid-Atlantic Bight (17.4 ± 15.1 m; Table 2-8).

Sixty-two percent of satellite-tagged juvenile Northern Gannets entered the Mid-Atlantic study area (21 of 34 birds), with individuals arriving from early October (10 October) to mid-November (14 November). Of these, 8 birds moved relatively quickly through the Mid-Atlantic study area, spending on average 13.9 ± 7.0 days there before moving south to eastern Florida (*n* = 4) and the Gulf of Mexico (*n* = 4). The remaining 13 individuals were still in the study area when their device stopped transmitting, with time spent ranging from 1 to 41 days. Thirty-eight percent (*n* = 13) of juveniles never transmitted locations within the Mid-Atlantic study area, potentially due to premature device loss, though two individuals persisted in deep, off-shelf waters on the southern Grand Bank of Newfoundland well into late fall (25 November and 20 December; Figure 2-21).

2.5 Discussion

The identification of priority habitats for seabirds in order to inform effective strategies for minimizing the adverse effects of offshore wind facilities requires comprehensive baseline information on their distribution, abundance, and patterns of habitat use (Winiarski et al. 2014). The vulnerability of a species to the hazards associated with offshore wind energy development (i.e. collision mortality and displacement), is determined largely by the scale and degree of exposure.

Satellite tracking of individual marine birds using PTTs is an effective method for remotely gathering high resolution locational data (Burger and Shaffer 2008). The low mortality rate observed in this study indicates that this method worked well for Northern Gannets, particularly the abdominally-implanted tags, allowing us to track widely-roaming birds throughout the year (unlike traditional surveys which only provide snapshots in time in limited conditions).

Northern Gannets spend a considerable portion of the year in U.S. waters, and roam widely over shelf waters and beyond (Fifield et al. 2014, Kinlan et al. 2016). The results of this study, however, indicate that Northern Gannets largely confined their winter habitat use to coastal areas, remaining largely inshore of the Federally-designated offshore WEAs and Lease Areas in the Mid-Atlantic study area. In winter, tracked Northern Gannets exhibited greater use of colder, shallower and productive waters. In general, males ventured closer to shore than females in winter.

In this study, the heaviest use of the Atlantic coastline was observed in shallower inshore waters and large bay mouths within the Mid-Atlantic study area, including the New York/New Jersey Bight, Chesapeake Bay, Pamlico Sound, and Onslow Bay. A few birds ventured further south to winter off the Florida coast and in the Gulf of Mexico. This wintering distribution may be influenced by the specific capture locations, however, and may not fully represent the entire Northern Gannet population in the region.

Overall, usage of any single WEA represented a very small fraction of the total of any seasonal distribution of Northern Gannets examined in this report (< 1% of total home range - 95% UD). Even overlap of all combined WEAs and Lease Areas with Northern Gannet distributions made up a small portion of the total for the season with highest overlap (< 5% for home range - 95% UD). It is important to note, however, that the distributions derived from this study only represent seasonal use by those sampled individuals during the years of our study. Estimates of spatial distribution do not account for inter-annual variability in distribution, differences in use among age-class or sexes, or any of the complex interactions among these variables for the Northern Gannet population as a whole. Furthermore, the observed percentage of WEAs and Lease Areas overlapping UDs within a season by may not fully capture how birds are using the space within that entire time period. For example, although a WEA may represent < 1% of the core use area, this does not necessarily indicate the rate at which birds transited the WEA, or the proportion of time spent within that WEA. The dbbmm models provide information about the potential for exposure at WEAs and Lease Areas, and do not consider the influence of additional factors contributing to risk, such as flight height and behavior.

Preliminary work conducted with GPS-GSM tags during the spring migration of 2016 (Chapter 6) indicates that individual variation in Northern Gannet movements may be an important consideration for future study. GPS-GSM technology produced hourly data for a small sample of Northern Gannets, giving us a clearer indication of how birds used the WEAs around Rhode Island and Massachusetts prior to migrating across the Gulf of Maine. Of seven birds tagged, two did not cross any of the seven WEAs in this area, while the others crossed several. Some birds spent less than four hours in the area, which may have not have been detected by PTTs, while others spent several days there before crossing the Gulf of Maine.

Winter habitat use by Northern Gannets is influenced by prey availability. Northern Gannets target surface-schooling pelagic fishes and squids throughout the year, and their distributions during the non-breeding season to some degree reflect the distribution of these prey. Northern Gannets handled at winter capture sites have regurgitated Menhaden (Brevoortia spp.). Menhaden is a key forage species along the U.S. Atlantic coast and in the Gulf of Mexico (Franklin 2007). The species is likely an important winter prey for Northern Gannets, as it is for other marine birds and mammals in the region. Menhaden occur year-round in the inshore waters of the Atlantic coast. Coastal bays provide nurseries for juvenile menhaden, most notably the Chesapeake Bay, the outer reaches and mouth of which is a major focus of commercial fishing vessels targeting this species on the Atlantic coast (SEDAR 2015). Juvenile and immature fish remain in the bays until autumn when they move to sea (see https://chesapeakebay.noaa.gov/fish-facts/menhaden). Schools engage in southward migration during autumn and early winter, with most menhaden moving to North Carolina, where they remain until March and early April. From March through May, menhaden spawn on the shelf waters off the bays.

Our Northern Gannet tracking data exhibit notable spatial and temporal correspondences with menhaden distributions (SEDAR 2015). Future studies aimed at Northern Gannet distributions during winter along the eastern seaboard and in the Gulf of Mexico would benefit from systematic prey collections coupled with tracking studies (see Chapter 7).

During their spring and fall migration, Northern Gannets use OCS waters more broadly, and sometimes for extended periods. As such, their distribution overlapped considerably with WEAs at these times, thus, the exposure of Northern Gannets to potential offshore wind projects on the Atlantic coast is much more likely during migration than in winter. During the spring migration, Northern Gannets generally left the study area in early May and exhibited a rapid northern movement on a broad front across the OCS, utilizing shelf waters and outer shallow banks. Their return migration in the fall was more protracted, and much more tied to coastal waters, with a few individuals wandering well out over the shelf slope, making brief visits to outer banks and sea mounts.

Juveniles wander more widely than adults after their initial colony departure, and often move as far as the southern reaches of the species' range in the Gulf of Mexico (Montevecchi et al. 2011). Satellite tagged juvenile Northern Gannets followed this pattern. After initial departure from their natal colony, juveniles dispersed widely offshore, in shelf and coastal waters, with some individuals making extended use of offshore waters south of Newfoundland. Similar to migrating adults, juveniles moved closer to the coast as they moved further south, and remained within the bounds of OCS waters. The first juveniles arrived in the Mid-Atlantic study area in early October, with some individuals moving very quickly through the area, and onto southern wintering locations in eastern Florida and the Gulf of Mexico. While in the Mid-Atlantic study area, juveniles ranged more extensively over OCS waters than migrating adults, and occupied relatively deeper waters. As such, juveniles may experience greater overlap with WEAs in the latter stages of dispersal, during which exposure to potential offshore wind projects on the Atlantic coast may be high.

Northern Gannets mature slowly and generally delay breeding until they are 5–6 years of age, and immature birds may remain in subtropical waters for up to three years before returning to the breeding grounds (Mowbray 2002). Based on this behavior, and the results of this tracking work, individual juvenile and immature birds may experience greater exposure to offshore wind facilities year-round than adults, because they do not confine their movements to shallower inshore areas in winter and generally wander more widely across the OCS year-round.

In contrast to findings in other studies, Northern Gannets remained entirely at sea during both migrations, and did not cross the relatively narrow isthmus between the Gulf of Maine and the Gulf of St. Lawrence to reach colonies there, choosing instead to go around the coast of Nova Scotia. Northern Gannets breeding in the UK can cross overland, but are known to have done so in only a few specific cases. For example, Northern Gannets on foraging trips from the colony on Ailsa Craig in the Firth of Clyde, Scotland, regularly cross the Kintyre Peninsula to forage in Machrihanish Bay, on the Atlantic side, a distance of 8 km overland (Maguire et al. 2017). Geolocator data also indicate that one migratory Northern Gannet returning late to breed on the Bass Rock, off eastern Scotland, crossed overland from the Firth of Clyde to the Firth of Forth (Maguire et al. 2017). This represents a distance of around 50 km overland, similar to that between the upper reaches of the Bay of Fundy in the Gulf of Maine and the Northumberland Strait in the Gulf of St. Lawrence.

Despite being highly ranked as vulnerable to the impacts of offshore wind development, based on their limited maneuverability, flight height, etc. (Langston 2010), recent studies in Europe suggest that Northern Gannets exhibit a strong avoidance of offshore wind turbines (Johnston et al. 2014, Vanermen et al. 2015, Garthe et al. 2017). As a result of this behavior, Northern Gannets are potentially more vulnerable to habitat loss, due to displacement from optimal foraging habitat, than to direct mortality due to collision. Most studies of Northern Gannet interactions with offshore wind facilities have been carried out during breeding, when individuals may become familiar with the location of turbines during frequent chick-provisioning and/or foraging trips (Garthe et al 2017). It is possible that birds, which encounter offshore wind facilities only infrequently during migration, would have less familiarity with such facilities, affecting avoidance rates particularly in poor visibility conditions. Understanding of how migrating Northern Gannets will respond to cumulative impacts of multiple offshore facilities is, thus, currently limited, particularly during poor visibility.

The high degree of uncertainty in estimating impacts of exposure on collision risk, and understanding population consequences of displacement highlights the need for information that can be used to improve the reliability of future model predictions (Bailey et al. 2014). Therefore, it is essential that plans to acquire empirical data on seabird responses during the construction and post-construction phases of new Lease Areas are incorporated into development proposals. Prior to construction, strategic planning can help mitigate the potential effects of offshore wind energy development by making informed siting decisions based on the results of this and other baseline studies of animal populations in the Mid-Atlantic region. Integrating this type of information will help to identify region-specific priority sites for development to attempt to minimize adverse effects, such as displacement, owing at times to ocean windscapes that are exploited by both wind-energy developers and marine birds during migration (Kranstauber et al. 2016; see Chapter 7). Drewitt and Langston (2006) noted that, whenever possible, developers should avoid areas where high densities of wintering and migratory seabirds occur, particularly for species of conservation concern. In order to better understand the potential effects of offshore wind energy development on birds, baseline information provided by our study could be utilized to distinguish the results of offshore energy development from natural variation in bird abundance during future post-construction monitoring efforts (Fox et al. 2006).

Table 2-1. Argos location classes and their assigned errors in meters used in the dynamic Brownian bridge movement models.

Argos location class	Mean error (m)
3	1,500
2	3,300
1	7,600
0	17,200
A	15,000
B	20,900
Z	18,600

Table 2-2. The number of adult Northern Gannets captured in this study at each of the capture sites in each year, 2012–2015.

Capture Site	**2012**	**2013**	**2014**	**2015**	**Total**
Cape St. Mary's	9	.	.	.	9
Delaware Bay	3	2	2	.	7
Chesapeake Bay	3	12	13	20	48
Pamlico Sound	.	6	5	.	11
Total	15	20	20	20	**75**

Table 2-3. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 95% "home range" utilization distribution (UD) of adult Northern Gannets on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (UD area in sq. km)	Fall migration (667,983.5)		Winter (187,645.6)		Spring migration (574,150.6)	
WEA/Lease Area names (area in sq. km)	%WEA/Lease Area w/in UD	% total UD area overlapped	%WEA/Lease Area w/in UD	% total UD area overlapped	%WEA/Lease Area w/in UD	% total UD area overlapped
MA OCS-A 0478 (119.1)	100	0.02	100	0.06	100	0.02
RI / MA OCS-A 0486 (394.6)	100	0.06	100	0.21	100	0.07
MA OCS-A 0501 (675.6)	100	0.1	26.14	0.09	100	0.12
MA OCS-A 0500 (759.0)	100	0.11	22.14	0.09	100	0.13
RI / MA OCS-A 0487 (272.2)	100	0.04	79.69	0.12	100	0.05
MA OCS-A 0502 (1004.1)	100	0.15	0	0	100	0.17
MA OCS-A 0503 (569.1)	100	0.09	0	0	100	0.1
NY Proposed Commercial Lease Unsolicited (165.6)	100	0.02	100	0.09	100	0.03
NY OCS-A 0512 (321.2)	100	0.05	100	0.17	100	0.06
NJ OCS-A 0499 (742.1)	100	0.11	100	0.4	100	0.13
NJ OCS-A 0498 (649.9)	100	0.1	100	0.35	100	0.11
DE OCS-A 0482 (390.5)	100	0.06	100	0.21	100	0.07
MD OCS-A 0489 (132.6)	100	0.02	100	0.07	100	0.02
MD OCS-A 0490 (190.2)	100	0.03	100	0.1	100	0.03
VA OCS-A 0483 (456.8)	98.87	0.07	100	0.24	78.16	0.06
VA OCS-A 0497 (8.6)	100	0	100	0	100	0
NC OCS-A 0508 (495.8)	70.1	0.05	100	0.26	0	0
SC Call Area - Grand Strand (2673.1)	60.21	0.23	100	1.35	0	0
NC WEA - Wilmington West (208.6)	100	0.03	100	0.11	0	0
NC WEA - Wilmington East (540.1)	8.43	0.01	65.8	0.19	0	0
SC Call Area - Cape Romain (652.4)	96.3	0.09	73.1	0.25	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	82.97	1.43	70.93	4.37	58.45	1.18

Table 2-4. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 50% "core use" utilization distribution (UD) of adult Northern Gannets on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (Core area in sq. km)	Fall migration (85,560.9)		Winter (17,790.4)		Spring migration (77,512.2)	
WEA/Lease Area names (area in sq. km)	%WEA/Lease Area w/in core	% total core area overlapped	%WEA/Lease Area w/in core	% total core area overlapped	%WEA/Lease Area w/in core	% total core area overlapped
MA OCS-A 0478 (119.1)	0	0	0	0	75.14	0.12
RI / MA OCS-A 0486 (394.6)	2.45	0.01	0	0	96.11	0.49
MA OCS-A 0501 (675.6)	1.16	0.01	0	0	49.82	0.43
MA OCS-A 0500 (759.0)	0	0	0	0	54.27	0.53
RI / MA OCS-A 0487 (272.2)	0	0	0	0	100	0.35
MA OCS-A 0502 (1004.1)	0.09	0	0	0	5.91	0.08
MA OCS-A 0503 (569.1)	0.17	0	0	0	0	0
NY Proposed Commercial Lease Unsolicited (165.6)	0	0	0	0	13.47	0.03
NY OCS-A 0512 (321.2)	54.63	0.21	0	0	4.69	0.02
NJ OCS-A 0499 (742.1)	32.51	0.28	5.15	0.21	99.24	0.95
NJ OCS-A 0498 (649.9)	20.43	0.16	16.33	0.6	99.08	0.83
DE OCS-A 0482 (390.5)	2.8	0.01	0	0	100	0.5
MD OCS-A 0489 (132.6)	1.83	0	0	0	100	0.17
MD OCS-A 0490 (190.2)	0	0	0	0	46.13	0.11
VA OCS-A 0483 (456.8)	0	0	0	0	0	0
VA OCS-A 0497 (8.6)	0	0	0	0	0	0
NC OCS-A 0508 (495.8)	0	0	0	0	0	0
SC Call Area - Grand Strand (2673.1)	0	0	0	0	0	0
NC WEA - Wilmington West (208.6)	0.2	0	2.61	0.03	0	0
NC WEA - Wilmington East (540.1)	0	0	0	0	0	0
SC Call Area - Cape Romain (652.4)	0	0	0	0	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	5.04	0.68	1.3	0.84	30.97	4.62

Table 2-5. The number of Northern Gannets breeding at each colony, and the percentage of satellite-tagged birds that appeared to associate with those colonies. Note that the colony of association was not established for 15 tagged birds, and that 9 birds were captured at the Cape St. Mary's colony, likely inflating the percentage of tagged birds associated with that colony. Numbers in parentheses indicate only winter caught birds (i.e. percentages with colony-caught birds removed).

Region	Colony	No. breeding pairs[1]	% continental population	No. tagged birds	% tagged birds
Gulf of St. Lawrence	Bonaventure Island, Québec	59,586	51	39	65 (76)
	Bird Rocks, Magdalen Islands	30,010	26	8	13 (25)
	Gullcliff Bay, Anticosti Island	200	< 1	0	.
Atlantic	Cape St. Mary's, Newfoundland	14,789	13	11 (2)	18 (4)
	Funk Island, Newfoundland	9,987	8	1	< 2
	Baccalieu Island, Newfoundland	2,253	2	1	< 2
	Total	116,825	.	60 (51)	.

[1] Based on a comprehensive survey of North American colonies in 2009 (Chardine et al. 2013).

Table 2-6. Comparison of generalized linear models examining second order resource selection effects of habitat characteristics on the probability of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) winter home range use in the Mid-Atlantic Bight (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll *a*, dist = distance to shore, SED = sediment type, depth = water depth, SSS6 = 6-yr mean winter sea surface salinity). Models are ranked according to Akaike Information Criterion (AIC). The table shows the variables included in the model, number of estimated parameters (K), differences between model Akaike Information Criterion (ΔAIC), and AIC weights (w_i).

Model	***K***	**AICc**	**ΔAICc**	$\mathbf{w_i}$
SST10+CHLOR10+dist+SED	9	11822.6	0.00	0.63
depth+SST10+CHLOR10+dist+SED	10	11824.4	1.88	0.24
depth+SST10+CHLOR10+SSS6+dist+SED	11	11825.7	3.19	0.13
depth+SST10+CHLOR10+SSS6+dist	6	11844.2	21.60	0.00
depth+SST10+CHLOR10	5	12043.9	221.37	0.00
depth+SST10+CHLOR10+SSS6	4	12044.5	221.93	0.00
depth+SST10	3	12132.4	309.88	0.00
depth	2	12552.3	729.76	0.00
Null model	1	13288.5	1465.91	0.00

Table 2-7. Scaled estimated coefficients (β), odds ratios (OR), confidence intervals (CI), standard errors (SE), and P-values for the variables in the top AIC ranked generalized linear model predicting second order resource selection of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) winter home range within the Mid-Atlantic Bight (dist = distance from shore (km); SST10= 10-yr mean winter sea surface temperature; CHLOR10 = 10-yr mean winter chlorophyll a).

	Scaled β	***OR***	***CI***	***SE***	***P***
(Intercept)	-1.19	0.30	0.25–0.37	0.11	<.001
SST10	-0.40	0.67	0.62–0.72	0.04	<.001
CHLOR10	0.23	1.26	1.18–1.34	0.03	<.001
dist	-0.63	0.53	0.49–0.58	0.04	<.001
Sediment grain size					
0.03 - 0.17 mm Sand	0.41	1.50	1.21–1.87	0.11	<.001
0.17 - 0.35 mm Sand	0.51	1.67	1.35–2.08	0.11	<.001
0.35 - 0.36 mm Sand	0.27	1.32	1.00–1.74	0.14	.053
0.36 - 0.48 mm Sand	0.42	1.52	1.18–1.96	0.13	.001
0.48+ mm Gravel	0.36	1.43	1.12–1.84	0.13	.004

Table 2-8. Comparison of estimated means (SD) of habitat characteristics measured at used locations in the winter home ranges of adult Northern Gannets (*n* = 31; 17 females, 12 males, 2 unknown) versus randomly generated available locations within the Mid-Atlantic Bight.

	Used		**Available**	
Habitat Variable	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
Water depth (m)	17.38 (15.06)	1.30 – 405.8	39.70 (153.42)	0.80 – 2444.30
Distance from shore (km)	13.01 (13.65)	0.20 – 121.83	25.60 (23.66)	0.22– 149.41
10-yr mean winter sea surface temperature (°C)	6.54 (1.79)	4.12 – 19.48	8.02 (2.84)	4.09 – 20.42
10-yr mean winter chlorophyll *a* (mg/m^3)	7.61 (5.21)	0.56 – 26.07	4.56 (4.34)	0.33 – 26.07
6-yr mean winter sea surface salinity (PSU)	32.42 (0.94)	29.05 – 35.73	32.71 (0.81)	21.52 – 36.27

Table 2-9. Comparison of generalized linear mixed models examining the effect of habitat characteristics on the probability of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) third order resource selection of core use areas s within the Mid-Atlantic winter home range (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll a, dist = distance to shore, SED = sediment grain size, depth = water depth, SSS6 = 6-yr sea surface salinity).

Model	AICc	ΔAICc	w_i	R^2c
(1|animal)+SST10+CHLOR10+dist+sediment	11107.4	0.00	1	0.24
(1|animal)+depth+SST10+CHLOR10+SSS6+dist	11127.3	19.88	0	0.26
(1|animal)+depth+SST10+CHLOR10	11338.8	231.40	0	0.24
(1|animal)+depth+SST10+CHLOR10+SSS6	11339.3	231.85	0	0.24
(1|animal)+depth+SST10	11656.9	549.54	0	0.20
(1|animal)+depth (m)	12215.0	1107.57	0	0.14
(1|animal)	13065.8	1958.41	0	0.03
Null model	13292.3	2184.88	0	0.00

Table 2-10. Scaled estimated coefficients (β), odds ratios (OR), confidence intervals (CI), standard error (SE), and P-values of the fixed effects in the top AIC-ranked generalized linear mixed model predicting third order resource selection of Northern Gannet (*n* = 31; 17 males, 12 females, 2 unknown) core winter habitat use within the Mid-Atlantic winter home range (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll a). Animal ID was included as a random effect to allow the intercept to vary among individuals and results shown include: between-animal-variance (τ00); the number of individuals included in the model (Nanimal); and the intraclass correlation among habitat measurements at locations of the same animal (ICCanimal).

	Scaled β	*OR*	*CI*	*SE*	*P*
Fixed Effects					
(Intercept)	-1.28	0.28	0.18–0.43	0.23	<0.001
SST10 (°C)	-0.35	0.70	0.64–0.77	0.05	<0.001
CHLOR10 (mg/m^3)	0.71	2.04	1.85–2.24	0.05	<0.001
Distance from shore (km)	-0.69	0.50	0.46–0.55	0.05	<0.001
Sediment grain size					
0.03 - 0.17 mm Sand	0.40	1.50	1.18–1.90	0.12	<0.001
0.17 - 0.35 mm Sand	0.48	1.62	1.29–2.05	0.12	<0.001
0.35 - 0.36 mm Sand	0.20	1.23	0.91–1.65	0.15	0.077
0.36 - 0.48 mm Sand	0.35	1.41	1.08–1.86	0.14	<0.001
0.48+ mm Gravel	0.26	1.30	1.00–1.70	0.13	0.043
Random Effect					
$\tau_{00,\ \text{animal}}$			1.11		
N_{animal}			31		
ICC_{animal}			0.252		

Table 2-11. Estimated means (SD) of habitat characteristics measured at adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) locations in their winter core use (0.50) and home range (0.95) distributions.

	Utilization Distribution Isopleth			
	0.50		0.95	
Habitat Variable	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
Mean monthly chlorophyll a (mg/m^3)	5.17 (2.97)	0.26 - 26.71	3.47 (3.12)	0.18 - 57.25
10-yr mean winter chlorophyll a (mg/m^3)	7.60 (5.21)	0.56 - 26.07	4.56 (4.33)	0.33 - 26.07
Mean monthly SST (°C)	11.36 (4.12)	1.89 - 24.27	12.62 (4.34)	0.58 - 25.75
10-yr mean winter SST (°C)	6.55 (1.79)	4.12 - 19.48	8.02 (2.84)	4.10 - 20.42
Mean monthly SSS (psu)	32.86 (0.99)	20.00 - 36.11	33.28 (1.02)	20.00 - 36.47
6-yr mean winter SSS (psu)	32.43 (0.94)	29.04 - 37.73	32.71 (0.81)	21.52 - 36.27
Distance from shore (km)	13.00 (13.65)	0.20 - 121.83	25.59 (23.65)	0.22 - 149.41
Water depth (m)	17.40 (15.11)	1.30 - 405.80	39.71 (153.39)	0.80 - 2444.30

Table 2-12. Estimated means (SD) of habitat characteristics measured at locations of adult male (n = 12) and female (n = 17) Northern Gannets in their winter core use (0.50) and home range (0.95) distributions. Wilcoxon rank sums test results examining differences in habitat characteristics at locations of adult male and female adult Northern Gannets in their winter core use and home range distributions were considered significant at P values < 0.05.

	Kernel Density Estimate Isopleth					
Habitat Variable	**Females**	**Males**		**Females**	**Males**	
	0.5		**P**	**0.95**		**P**
Mean monthly chlorophyll *a* (mg/m^3)	5.26 (2.99)	5.36 (2.81)	0.038	3.14 (2.79)	4.58(3.69)	<0.0001
10-yr chlorophyll *a* (mg/m^3)	8.03 (5.59)	7.55 (3.94)	0.499	4.18 (4.05)	6.09 (4.92)	<0.0001
Mean monthly SST (°C)	11.20 (4.00)	12.51 (4.09)	<0.001	12.89 (4.29)	12.66 (4.12)	0.053
10-yr mean winter SST (°C)	6.44 (1.50)	6.43 (2.04)	0.050	8.22 (2.88)	7.27 (2.56)	<0.0001
Mean monthly SSS (psu)	32.83 (0.91)	32.80 (1.22)	0.090	33.40 (0.83)	32.87 (1.33)	<0.0001
6-yr winter SSS (psu)	32.26 (1.00)	32.78 (0.62)	<0.001	32.72 (0.76)	32.61 (0.89)	0.880
Distance from shore (km)	11.82 (8.90)	10.20 (6.02)	0.001	26.32 (21.83)	16.32 (13.85)	<0.0001
Water depth (m)	15.69 (7.62)	16.10 (10.78)	0.025	34.83 (119.25)	20.52 (13.65)	<0.0001

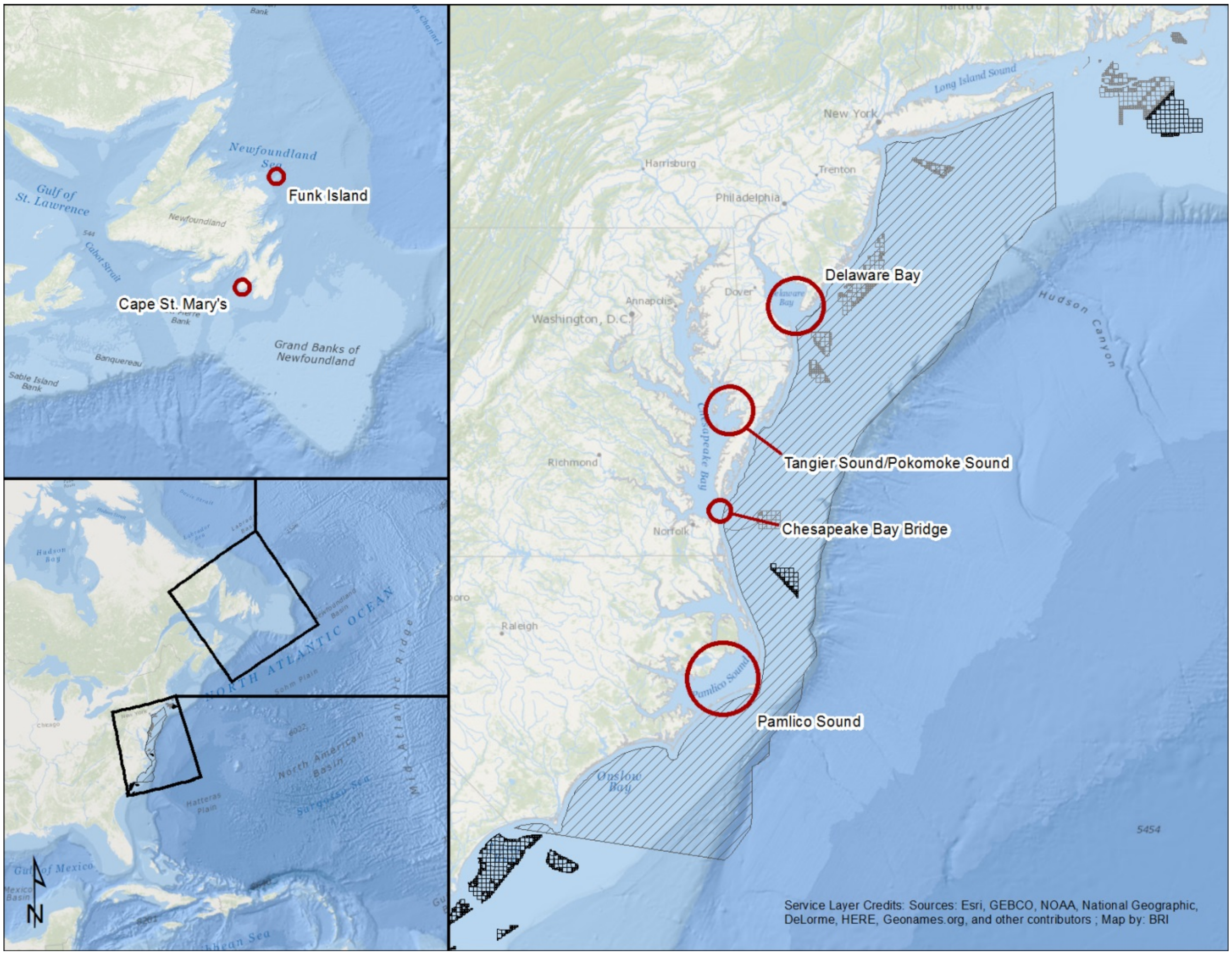


Figure 2-1. The Mid-Atlantic study area (hatched area, right map) and the locations of Northern Gannets captures (red circles) in this study (adults wintering in the Mid-Atlantic study area) and prior tracking work (juveniles leaving colonies in eastern Newfoundland, top left map). The federally designated Wind Energy Areas (WEAs) within and surrounding the study area are also included – light gray blocks = BOEM Lease Areas, dark gray blocks = BOEM Wind Planning Areas.

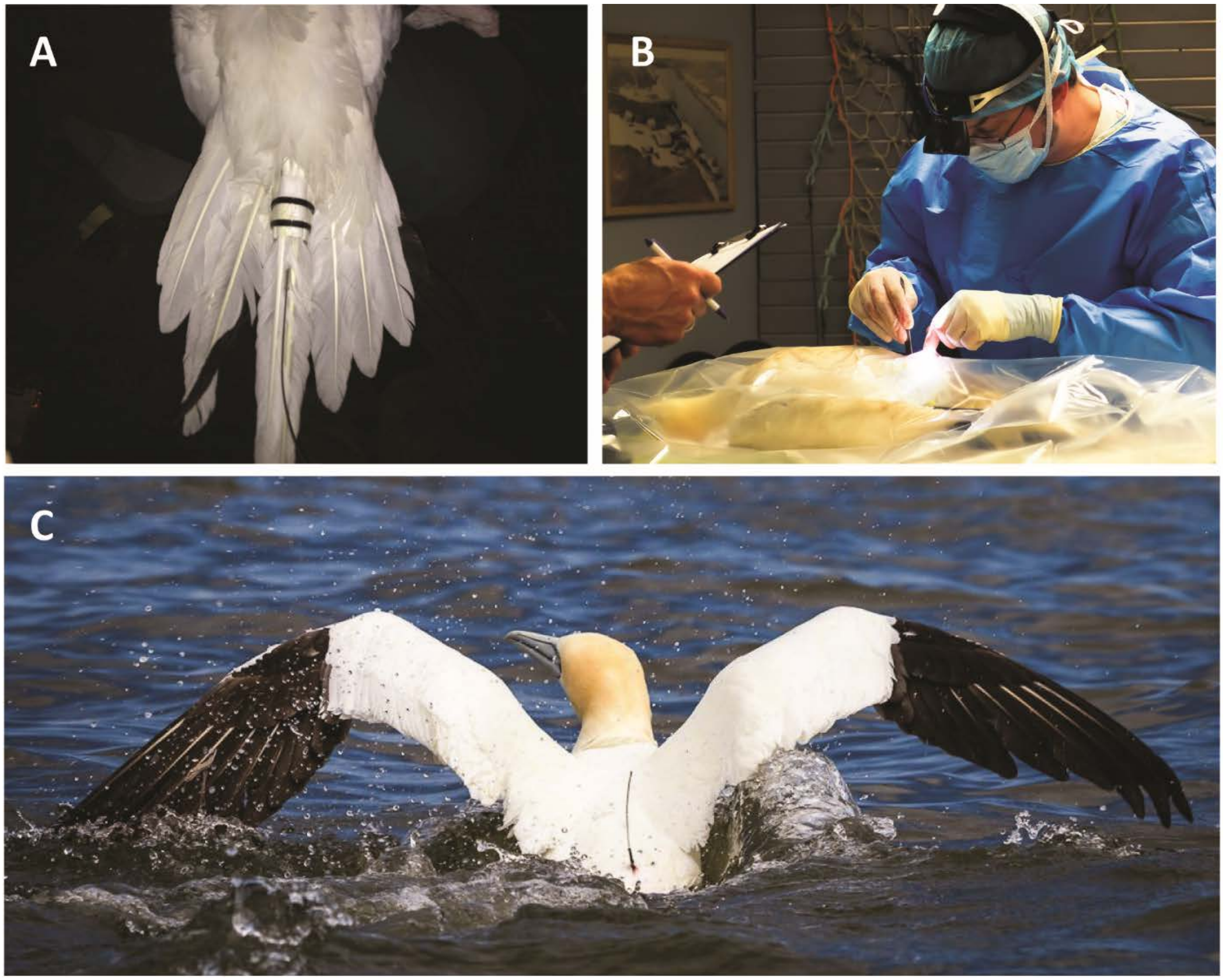


Figure 2-2. **(A)** dorsal view of a Northern Gannet with a satellite transmitter taped to the underside of the central tail feathers and the antenna passing up through the tail, **(B)** surgical implantation of a satellite transmitter by the project veterinarian, **(C)** a Northern Gannet with an implanted satellite transmitter being released in Delaware Bay, MD, with the protruding antenna clearly visible on the lower back. (Images: J. Fiely and C. Gray/BRI)

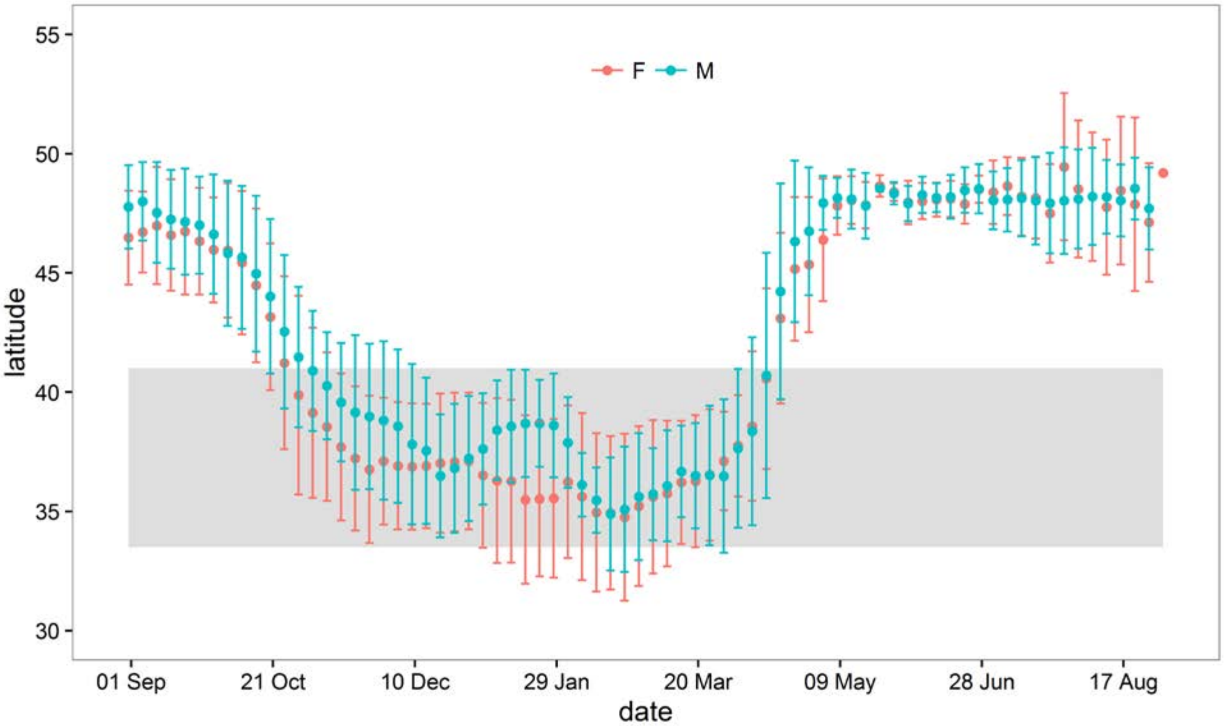


Figure 2-3. Mean latitude (± SD) for adult male and female Northern Gannets. Data includes all tagged adult birds (*n* = 75), from all years (*n* = 4), and the grey box represents latitudes that fall within the Mid-Atlantic study area.

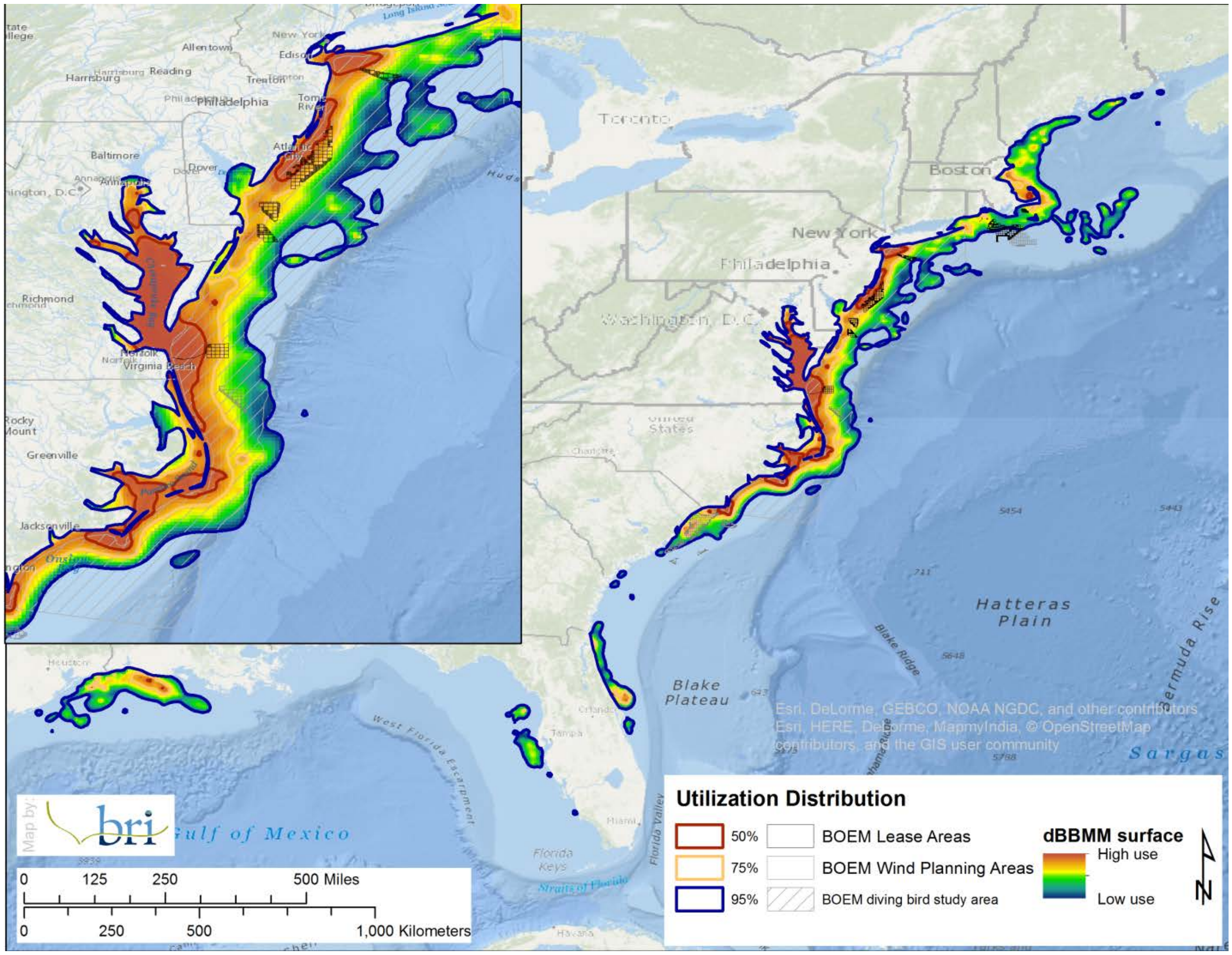


Figure 2-4. Complete winter distributions of adult Northern Gannets (*n* = 34) on the U.S. coast. Most birds wintered around the Mid-Atlantic region, with a few individuals venturing further south to winter in the Gulf of Mexico.

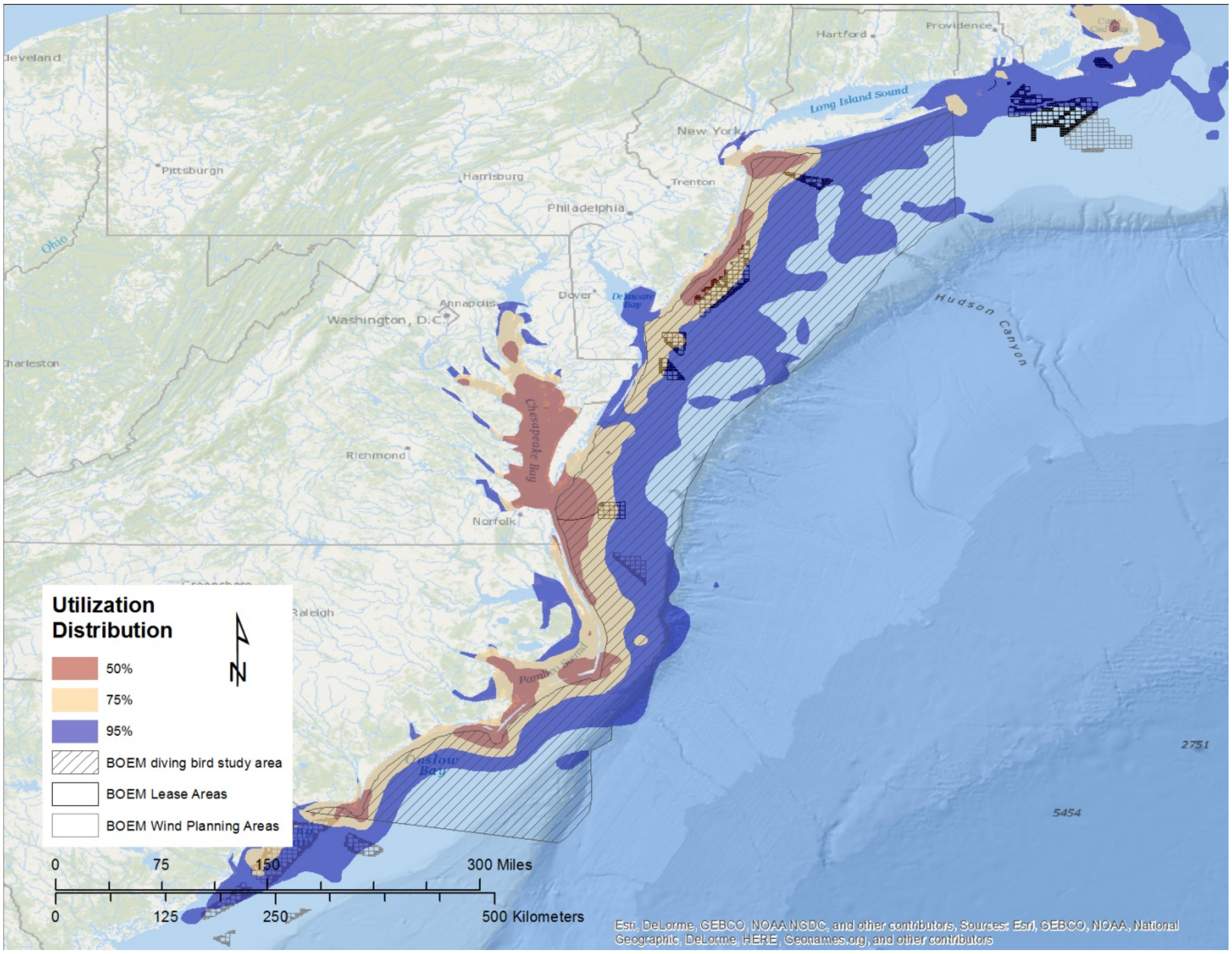


Figure 2-5. Winter distributions of satellite-tagged adult Northern Gannets (*n* = 34) zoomed in (from Figure 2-4) to highlight the Mid-Atlantic study area (hatched), including the mean winter home range (95% UD, blue) and core use areas (50% UD, red).

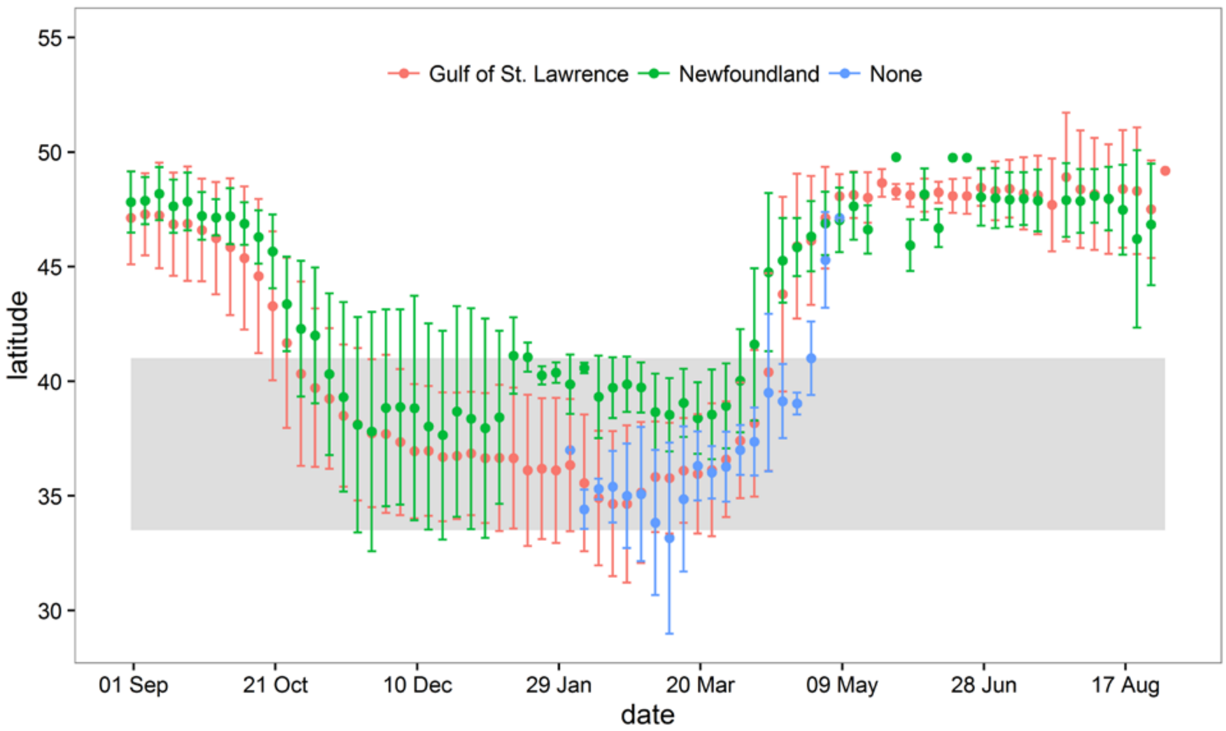


Figure 2-6. Mean latitude (± SD) for adult Northern Gannets from colonies in each region: the Gulf of St. Lawrence (red) and Newfoundland (green). ‘None’ (blue) indicates that an associated colony was not determined. Data includes all tagged birds (*n* = 75), from all years (*n* = 4), and the grey box represents latitudes that fall within the Mid-Atlantic study area.

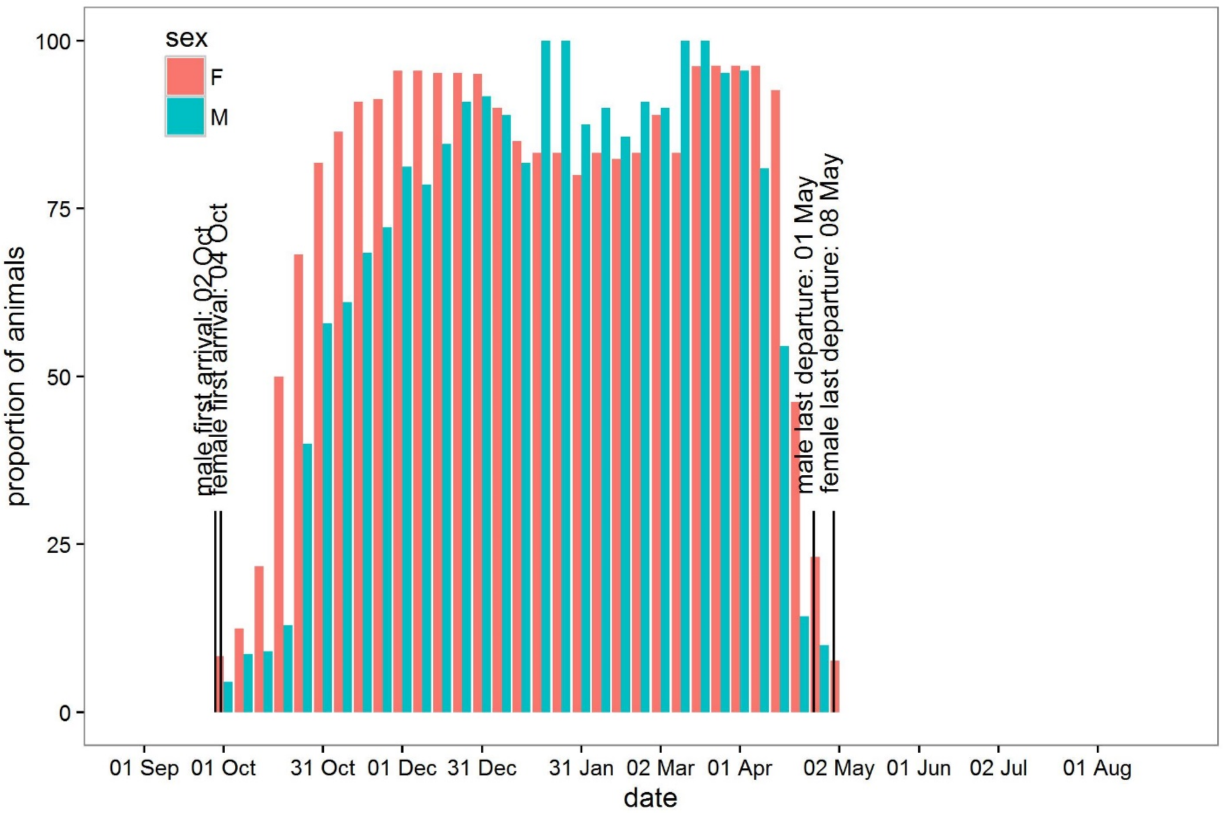
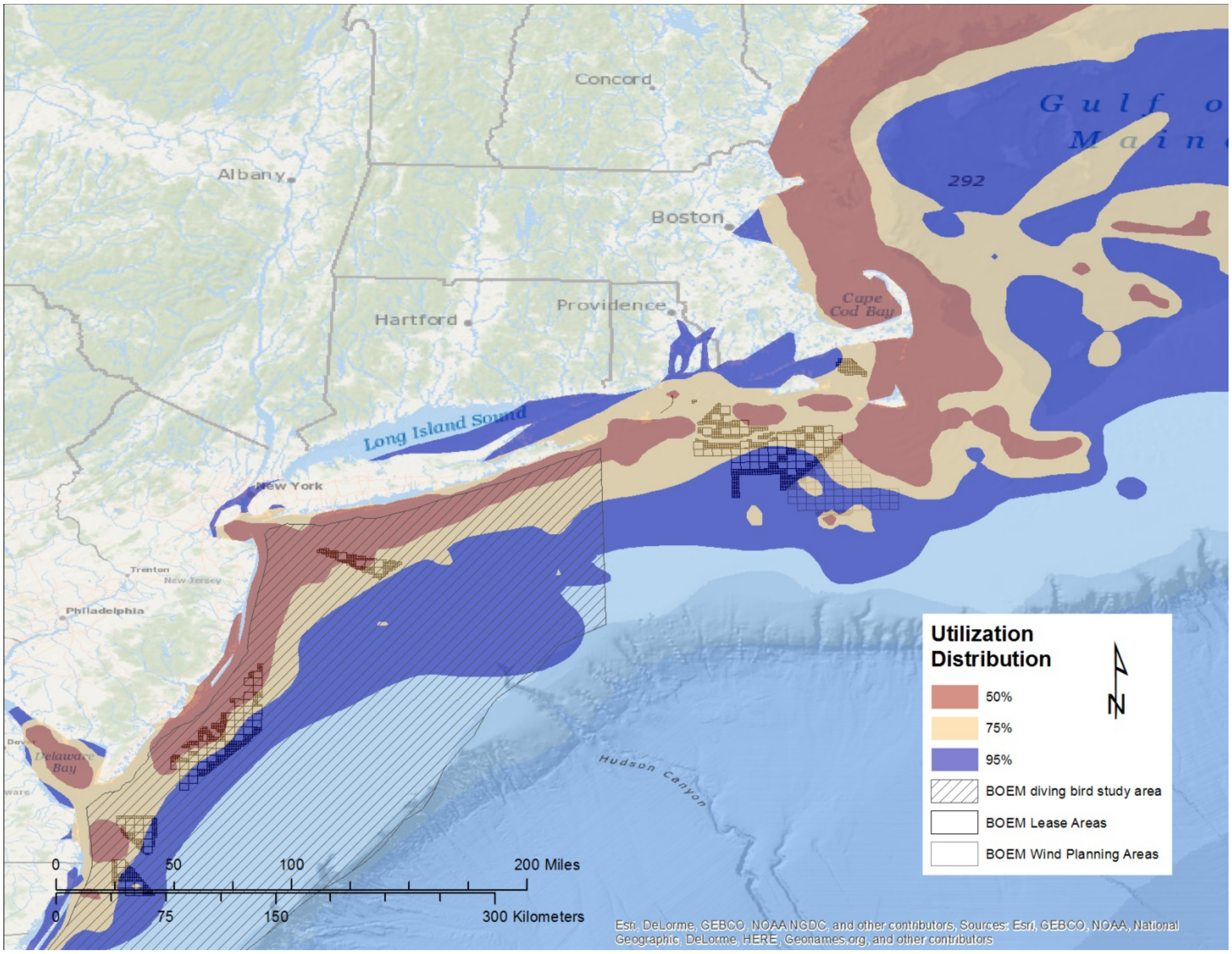


Figure 2-7. The proportion of adult male and female satellite-tagged adult Northern Gannets south of 41° N latitude and north of 33.5° N (the northern and southern boundaries of the study area), and the date of first arrival to and last departure from the Mid-Atlantic study area for each sex.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 2-8. Distributions of adult Northern Gannets (*n* = 36) during fall migration in the Mid-Atlantic and southern New England, 2012 - 2015. Intensity of use ranges from lowest areas of use (blue) to greatest areas of use (red).

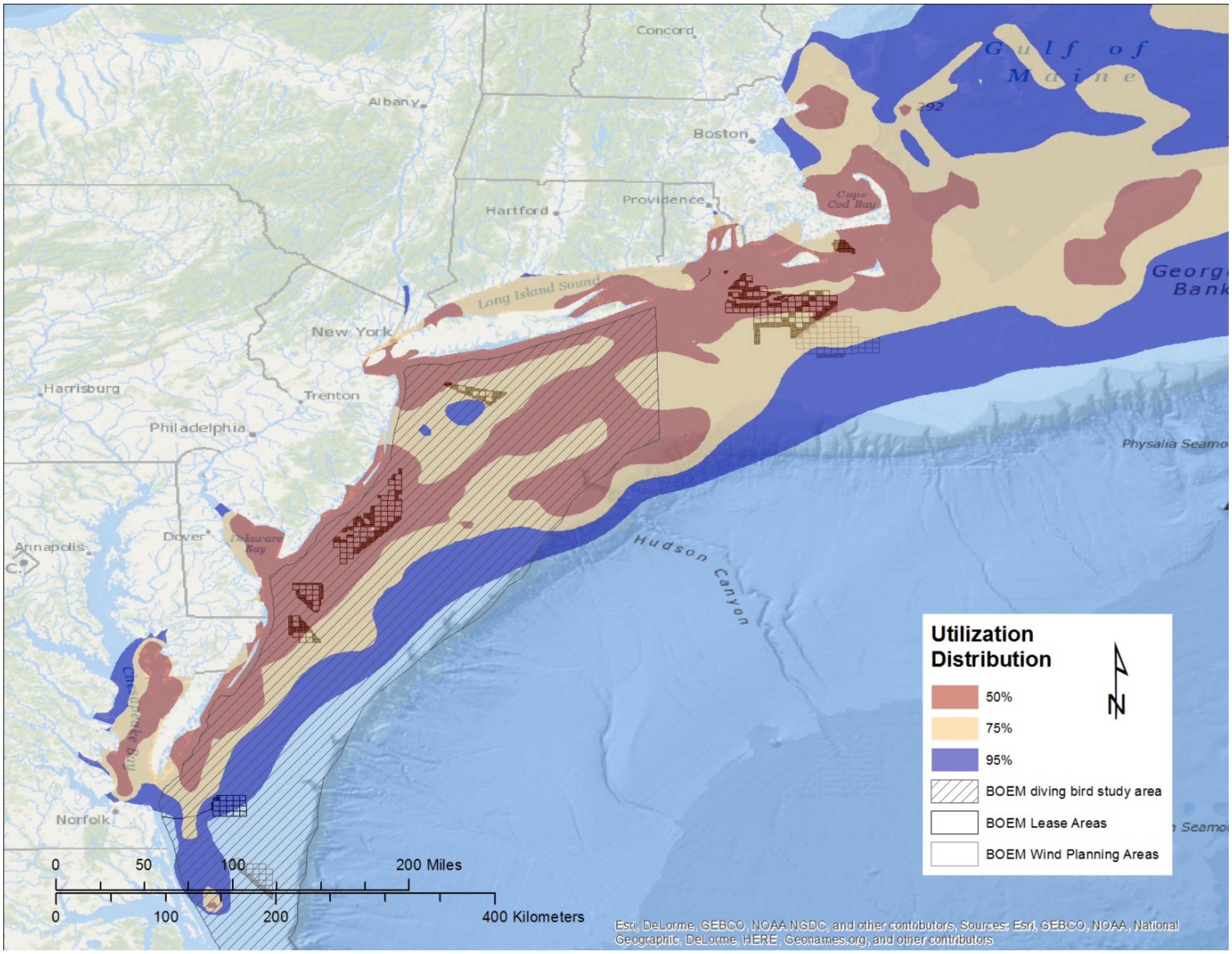


Figure 2-9. Distributions of adult Northern Gannets (*n* = 35) during spring migration in the Mid-Atlantic and southern New England, 2012–2015. Intensity of use ranges from lowest areas of use (blue) to greatest areas of use (red).

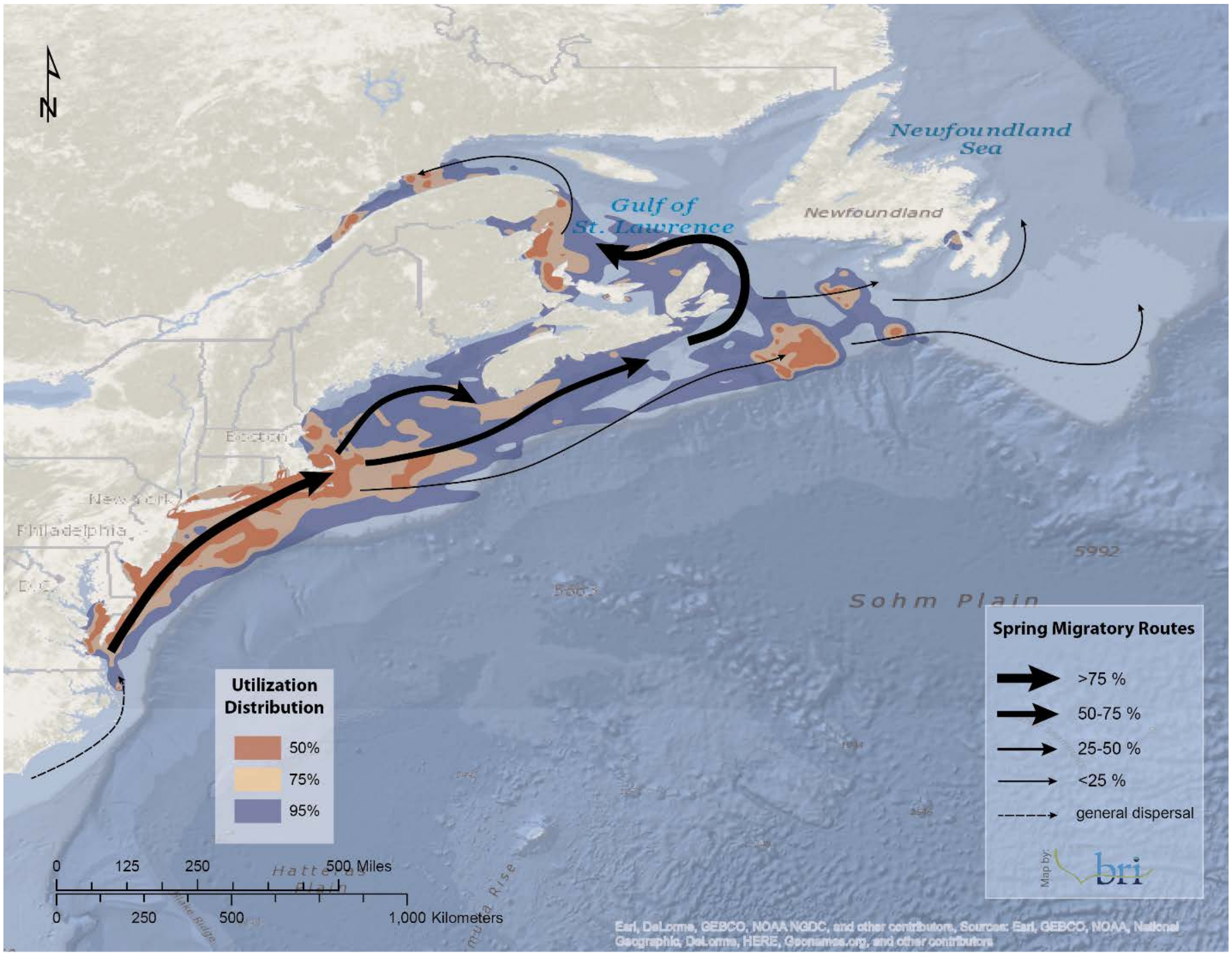


Figure 2-10. The northerly spring migration routes of adult Northern Gannets (*n* = 35), tagged with satellite transmitters in winter in the Mid-Atlantic study area (2012–2015) or at the Cape St. Mary's colony during breeding (2012), indicating a broad use of OCS waters and heavy use of outer banks.

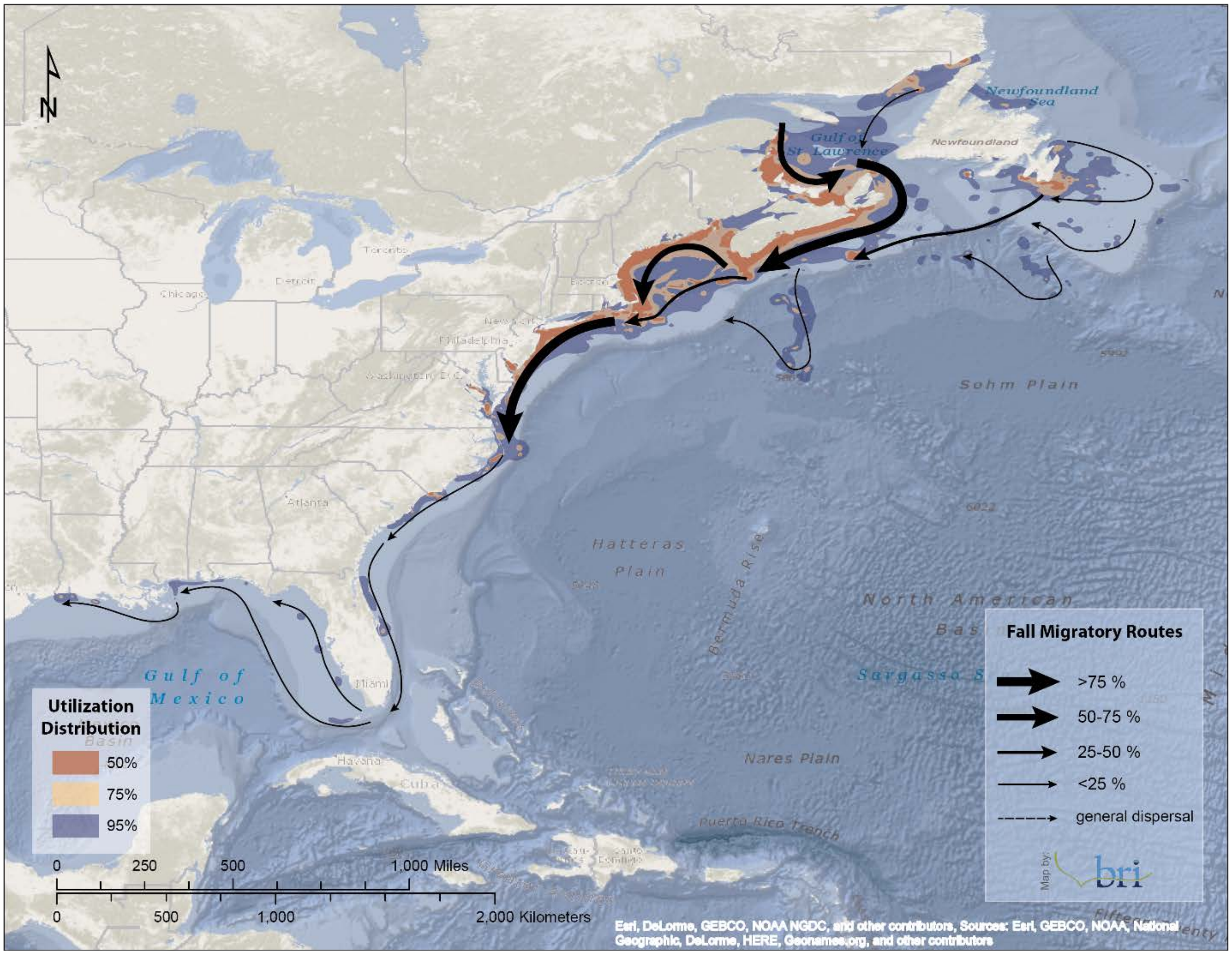


Figure 2-11. The southerly fall migration of adult Northern Gannets (*n* = 36), satellite-tagged in winter in the Mid-Atlantic study area or at the Cape St. Mary’s colony during breeding, indicating a heavy use of coastal waters, with a few individuals roaming over the OCS and even out over the shelf slope.

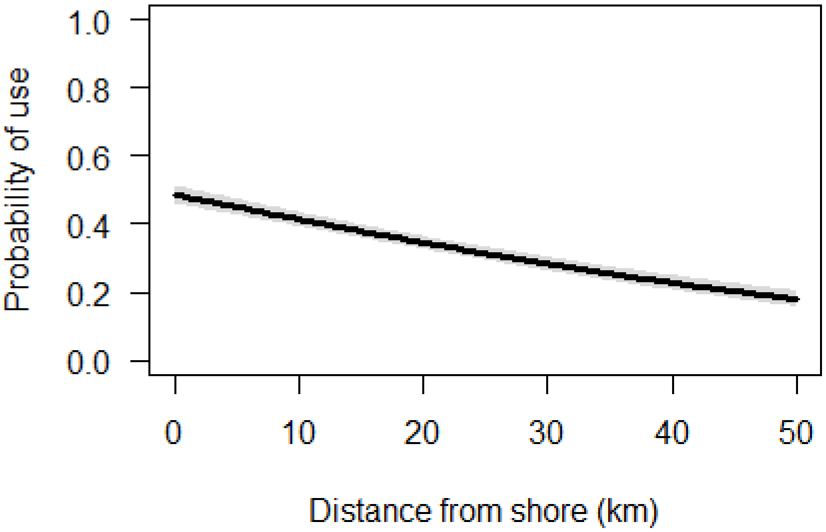


Figure 2-12. Generalized linear model results of the effect of distance from shore (km) on the probability of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) second order resource selection of the winter home range within the Mid-Atlantic Bight.

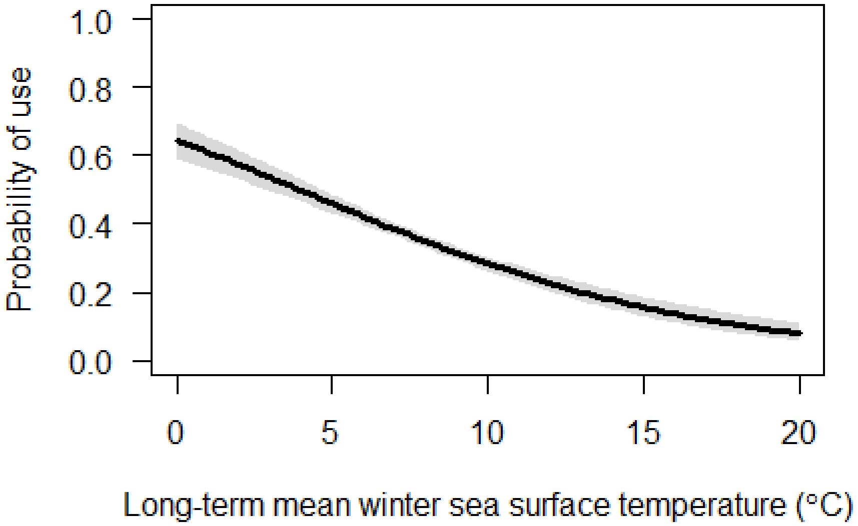


Figure 2-13. Generalized linear model results of the effect of long-term mean winter sea surface temperature (SST10) in °C on the probability of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) second order resource selection of the winter home range within the Mid-Atlantic Bight.

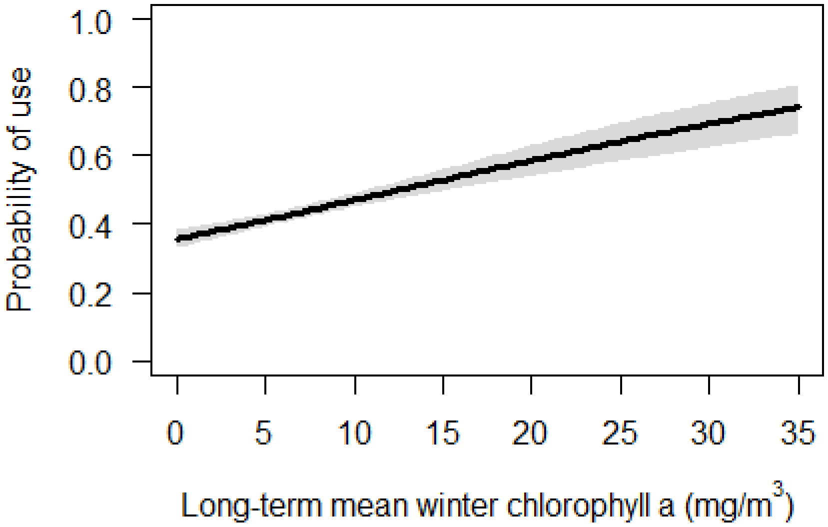


Figure 2-14. Generalized linear model results of the effect of long-term mean winter chlorophyll a (CHLOR10) in mg/m3 on the probability of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) second order resource selection of the winter home range within the Mid-Atlantic Bight.

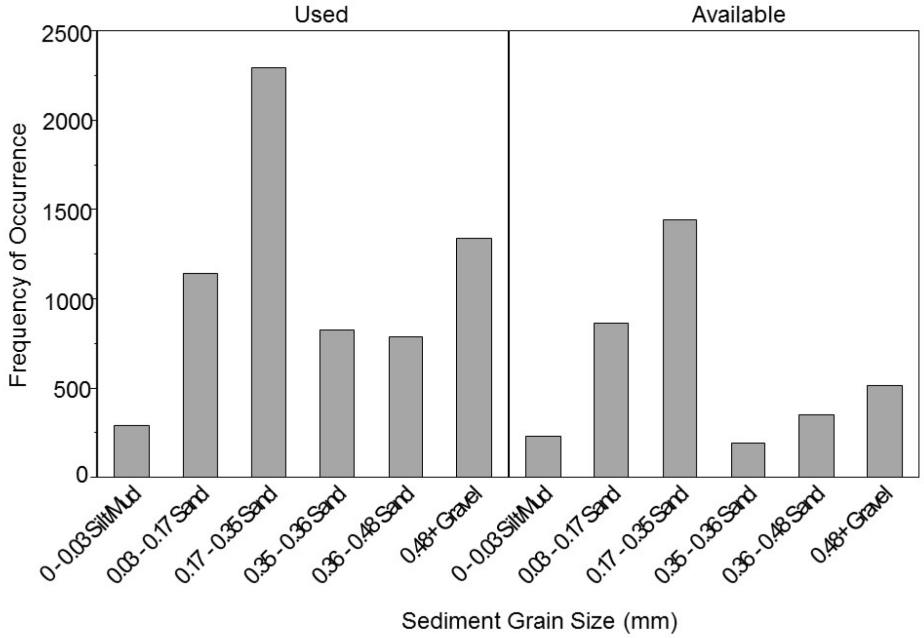


Figure 2-15. Frequency of occurrence among sediment grain sizes at used locations included in the generalized linear model predicting second order resource selection of adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) winter home range versus randomly generated available locations across the Mid-Atlantic Bight.

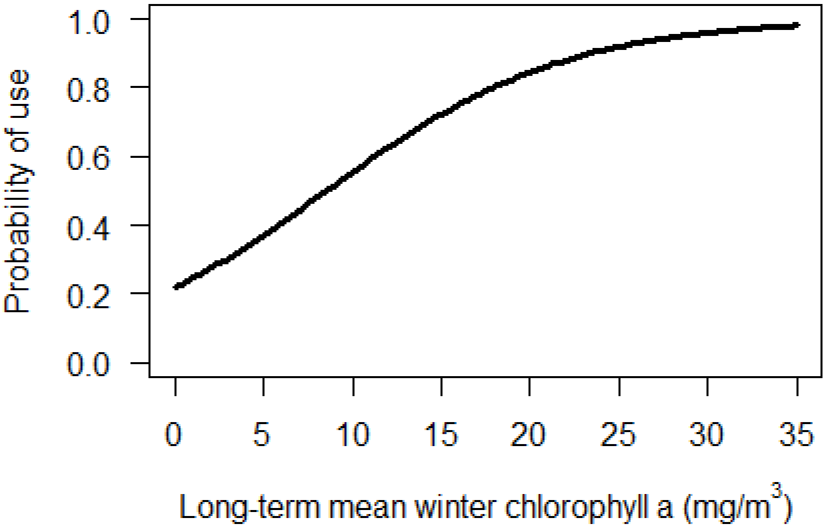


Figure 2-16. Generalized linear mixed model results of the effect of long-term mean winter chlorophyll a (CHLOR10) in mg/m3 on the probability of third order resource selection of core use areas by adult Northern Gannets (*n* = 31; 17 females, 12 males, 2 unknown) within the mid-Atlantic winter home range.

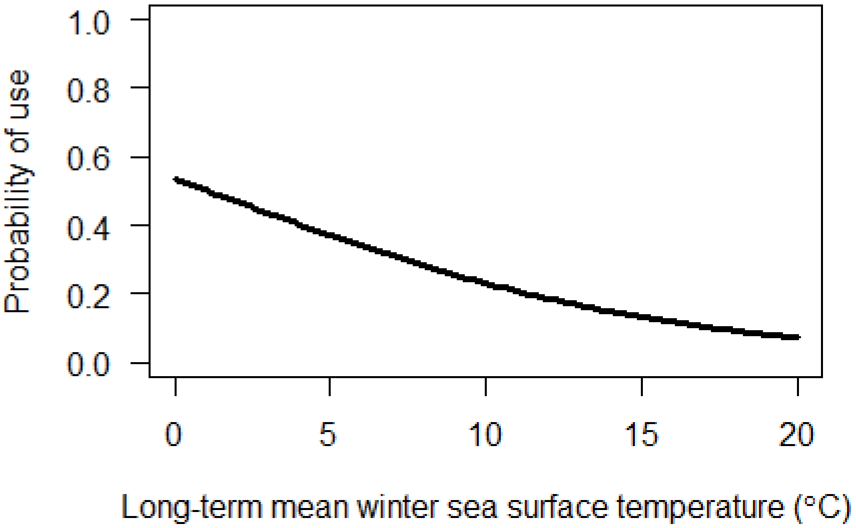


Figure 2-17. Generalized linear model results of the effect of long-term mean winter sea surface temperature (SST10) in °C on the probability of third order resource selection of core use areas by adult Northern Gannets (*n* = 31; 17 females, 12 males, 2 unknown) within the mid-Atlantic winter home range.

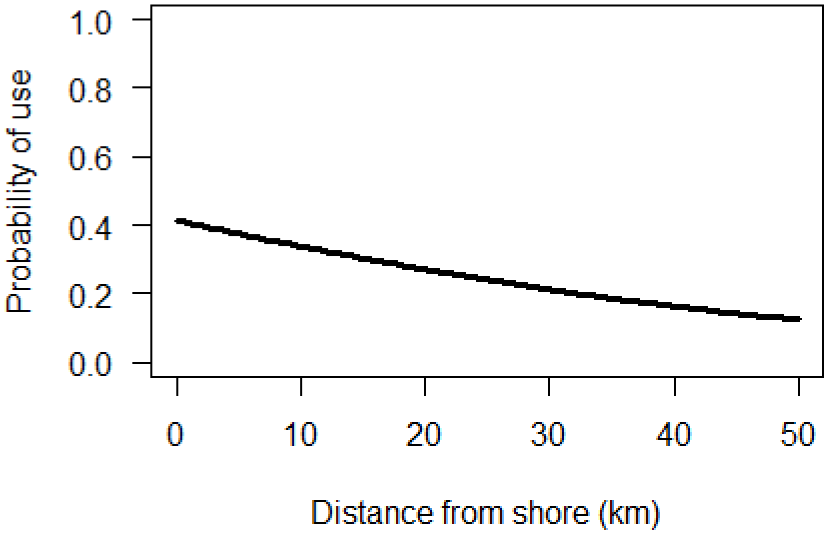


Figure 2-18. Generalized linear model results of the effect of distance from shore (km) on the probability of third order resource selection of core use areas by adult Northern Gannets (*n* = 31; 17 females, 12 males, 2 unknown) within the mid-Atlantic winter home range.

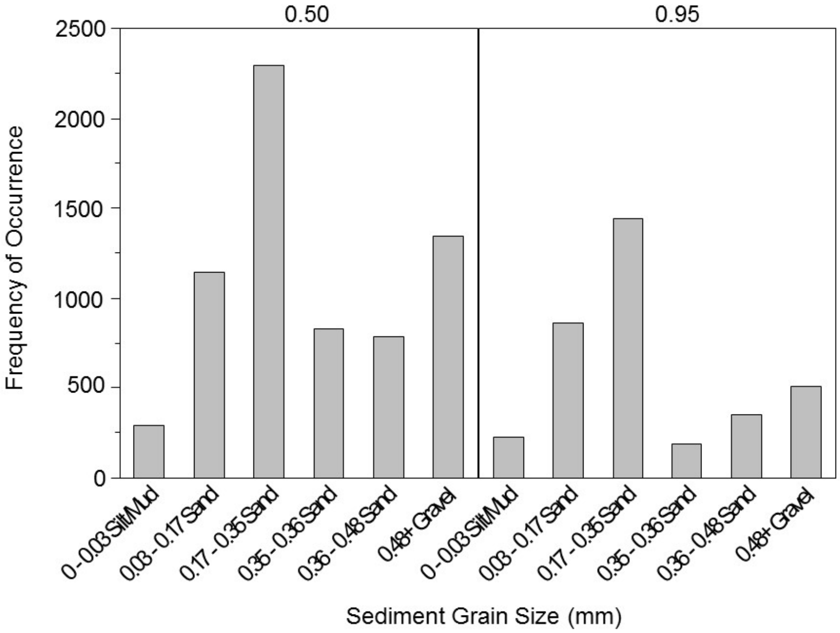


Figure 2-19. Frequency of occurrence among sediment grain sizes at adult Northern Gannet (*n* = 31; 17 females, 12 males, 2 unknown) locations within core use areas (0.50) versus locations throughout the mid-Atlantic winter home range.

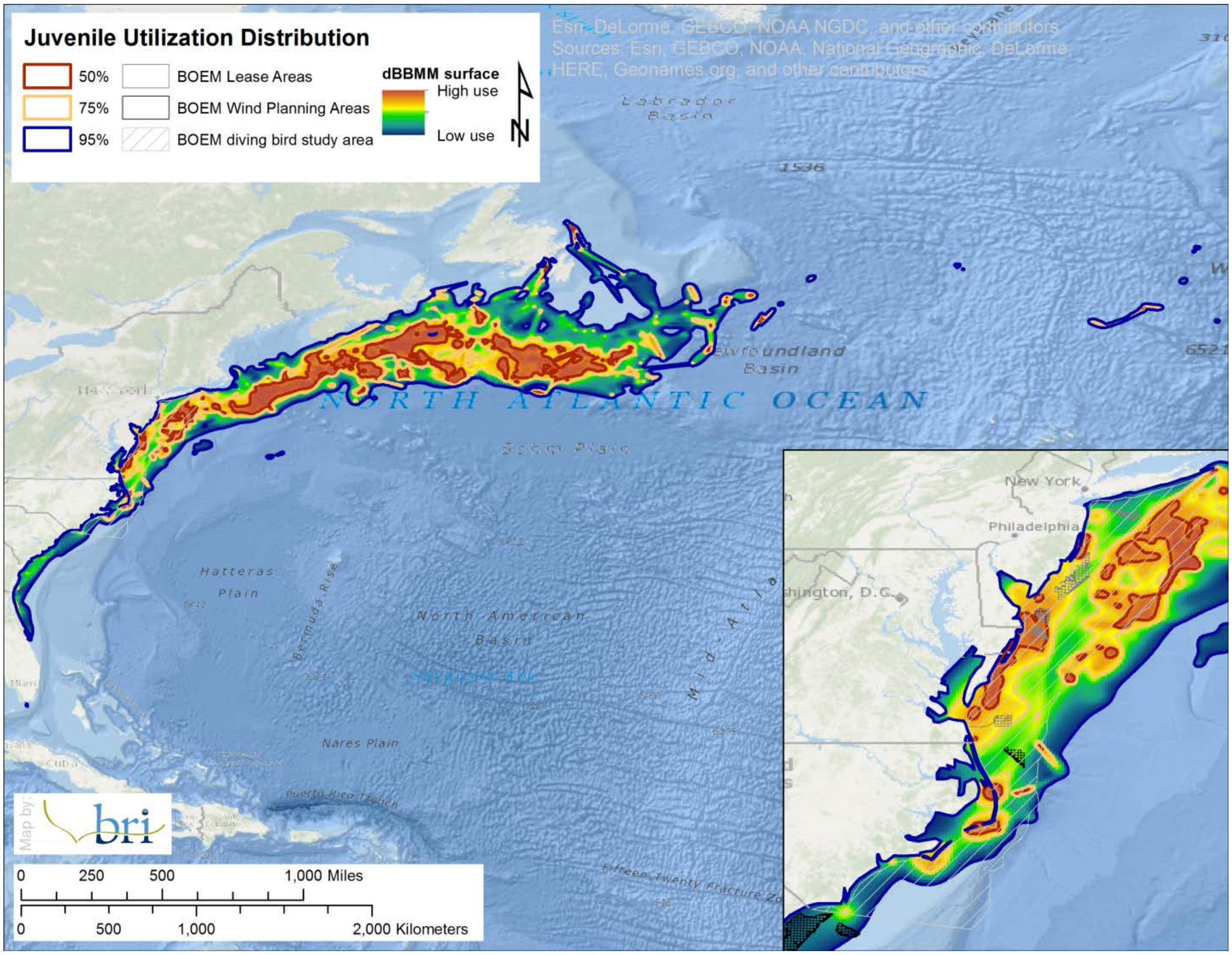


Figure 2-20. The distribution of satellite-tagged juvenile Northern Gannets (*n* = 34) during early fall (1 October – 15 November) dispersal from their colonies. One individual appeared to attempt a trans-Atlantic migration before turning around and tracking back to the west. This model was derived from data collected in 2008–2010, prior to this project.

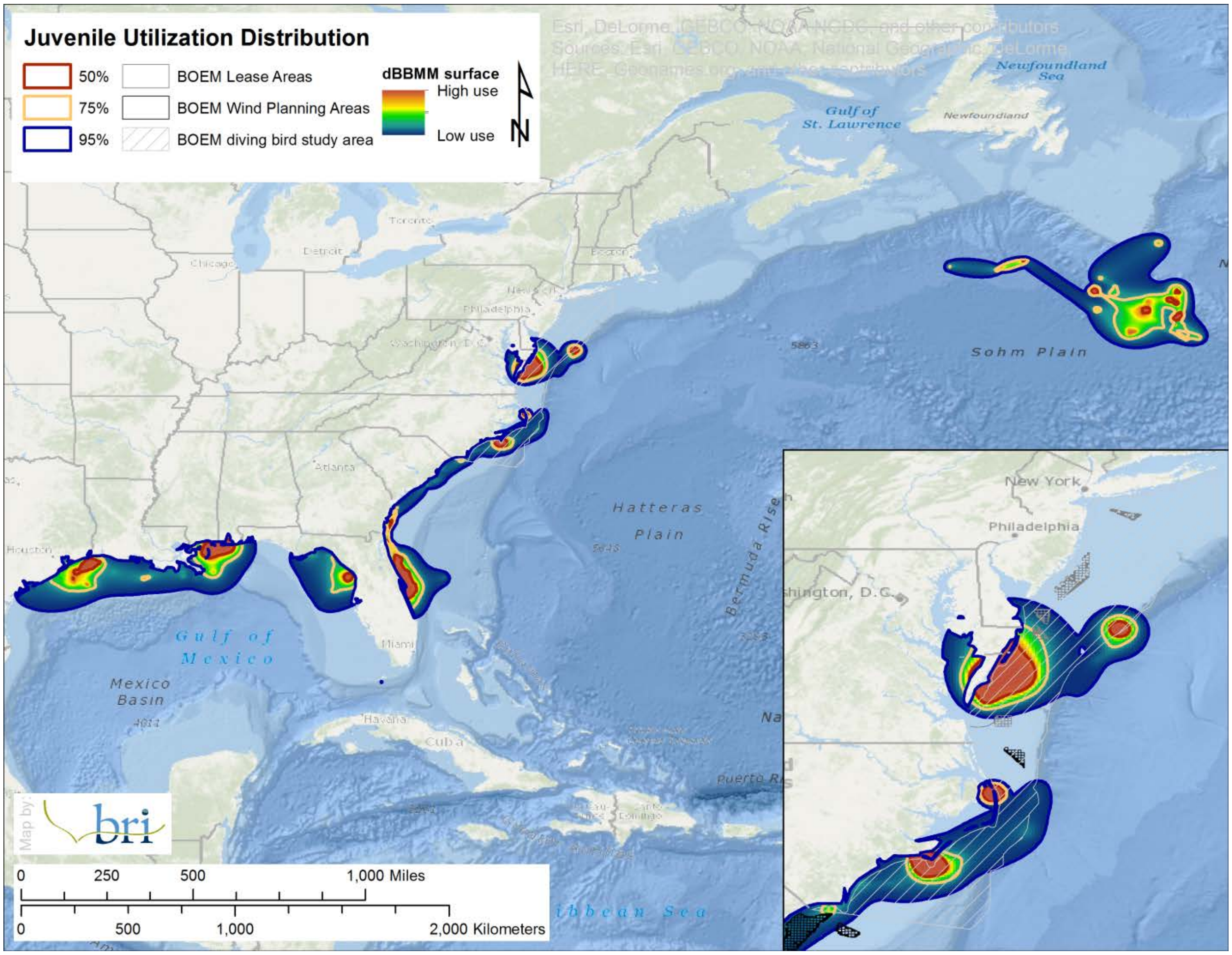


Figure 2-21. The distribution of satellite-tagged juvenile Northern Gannets (*n* = 12) during late fall (16 November - 31 December) dispersal from their colonies. Two individuals persisted in deep, off-shelf waters on the southern Grand Bank of Newfoundland well into late fall. This model was derived from data collected in 2008–2010, prior to this project.

Appendix A

Table A-1. Details of capture and satellite transmitter deployments for all adult Northern Gannets captured in this study, 2012-2015.

Tagging Date	Capture area	Tag ID	Tag Type	Tag Mount	Band Number	Age	Sex	Weight (g)	Date of Last Location	No. Tag Days	Bird/Tag Fate	Possible Reason	Associated Colony
03/08/12	Chesapeake Bay, MD	115866	PTT	Tail	1078-62622	A4Y	M	3,800	04/16/12	40	unk/tag fail	molted	unknown
03/09/12	Chesapeake Bay, MD	115867	PTT	Tail	1078-62623	A4Y	M	3,100	06/20/12	101	unk/tag fail	molted	Bonaventure
03/12/12	Chesapeake Bay, MD	115865	PTT	Tail	1108-07003	A4Y	F	3,500	09/06/12	176	unk/tag fail	molted.	Bonaventure
03/18/12	Delaware Bay, NJ	118161	PTT	Implant	1078-62624	A4Y	F	3,700	02/16/13	333	unk/tag fail	battery	Bonaventure
03/22/12	Delaware Bay, NJ	118160	PTT	Implant	1078-62625	A4Y	F	3,550	04/16/13	389	unk/tag fail	battery	Bonaventure
03/22/12	Delaware Bay, NJ	118162	PTT	Implant	1078-62626	A4Y	M	3,050	02/03/13	317	unk/tag fail	battery	Bonaventure
09/27/12	Cape St. Mary's, NL	115868	PTT	Tail	618-14993	ATY	F	3,050	11/28/12	62	unk/tag fail	molted.	*Cape St. Mary's
09/27/12	Cape St. Mary's, NL	115871	PTT	Tail	618-14994	ATY	M	.	11/18/12	52	unk/tag fail	molted	*Cape St. Mary's
09/27/12	Cape St. Mary's, NL	115872	PTT	Tail	618-14996	ATY	M	.	12/18/12	82	unk/tag fail	molted	*Cape St. Mary's
09/27/12	Cape St. Mary's, NL	115873	PTT	Tail	618-14992	ATY	M	2,675	12/22/12	86	unk/tag fail	molted	*Cape St. Mary's
09/27/12	Cape St. Mary's, NL	115876	PTT	Tail	618-14995	ATY	M	.	11/12/1	46	unk/tag fail	molted	*Cape St. Mary's
09/28/12	Cape St. Mary's, NL	115869	PTT	Tail	618-14999	ATY	M	.	11/22/12	55	unk/tag fail	molted	*Cape St. Mary's
09/28/12	Cape St. Mary's, NL	115870	PTT	Tail	618-14997	ATY	.	.	01/10/13	104	unk/tag fail	molted	*Cape St. Mary's
09/28/12	Cape St. Mary's, NL	115874	PTT	Tail	768-15710	ATY	M	.	11/09/12	42	unk/tag fail	molted	*Cape St. Mary's
09/28/12	Cape St. Mary's, NL	115875	PTT	Tail	618-15000	ATY	F	.	10/24/12	26	unk/tag fail	molted	*Cape St. Mary's
02/05/13	Chesapeake Bay, VA	123448	PTT	Implant	0960-87701	A4Y	M	3,350	02/16/13	10	mortality	surgery	unknown
02/05/13	Chesapeake Bay, VA	123447	PTT	Implant	0968-87702	A4Y	F	3,600	03/13/13	35	mortality	unknown	unknown
02/14/13	Pamlico Sound, NC	123449	PTT	Implant	0968-87704	A4Y	M	2,900	01/03/14	322	unk/tag fail	battery	Bonaventure
02/15/13	Pamlico Sound, NC	123454	PTT	Implant	0968-87705	A4Y	F	3,050	05/12/13	85	unk/tag fail	battery	unknown
02/15/13	Pamlico Sound, NC	123450	PTT	Implant	0968-87706	A4Y	F	3,500	12/27/13	315	unk/tag fail	battery	Bonaventure
02/18/13	Chesapeake Bay, VA	123451	PTT	Implant	0968-87707	A4Y	F	3,100	04/18/13	58	unk/tag fail	battery	unknown
02/18/13	Chesapeake Bay, VA	123453	PTT	Implant	0968-87708	A4Y	F	3,150	03/04/13	13	mortality	surgery	unknown
02/25/13	Pamlico Sound, NC	123452	PTT	Implant	2017-14901	ASY	F	3,100	03/03/13	6	mortality	surgery	unknown
02/26/13	Pamlico Sound, NC	123455	PTT	Implant	2017-14902	ASY	M	3,150	12/14/13	291	unk/tag fail	battery	Bird Rocks
03/04/13	Pamlico Sound, NC	123456	PTT	Implant	2017-14903	ASY	M	3,050	03/07/13	3	mortality	surgery	unknown
03/10/13	Delaware Bay, DE	123457	PTT	Implant	0968-87724	A4Y	M	3,000	02/26/14	352	unk/tag fail	battery	Bonaventure

03/10/13	Delaware Bay, DE	123458	PTT	Implant	0968-87725	A4Y	F	3,350	03/15/14	369	unk/tag fail	battery	Bird Rocks
03/15/13	Chesapeake Bay, VA	123459	PTT	Implant	0968-87709	A4Y	F	3,600	03/10/14	359	unk/tag fail	battery	Bonaventure
03/15/13	Chesapeake Bay, VA	123460	PTT	Implant	0968-87710	A4Y	M	3,400	03/19/14	368	unk/tag fail	battery	Bird Rocks
03/15/13	Chesapeake Bay, VA	123461	PTT	Implant	0968-87711	A4Y	M	3,300	10/28/13	226	mortality	unknown	Bonaventure
03/15/13	Chesapeake Bay, VA	123462	PTT	Implant	0968-87712	A4Y	M	4,050	06/20/13	96	unk/tag fail	unknown	Bird Rocks
03/16/13	Chesapeake Bay, VA	123463	PTT	Implant	0968-87714	A4Y	F	3,450	06/13/13	88	mortality	unknown	Bonaventure
03/16/13	Chesapeake Bay, VA	123464	PTT	Implant	0968-87715	A4Y	F	3,350	03/28/14	376	unk/tag fail	unknown	Bird Rocks
03/16/13	Chesapeake Bay, VA	123465	PTT	Implant	0968-87716	A4Y	M	3,500	03/19/13	2	mortality	surgery	unknown
03/16/13	Chesapeake Bay, VA	123466	PTT	Implant	0968-87717	A4Y	M	3,300	09/26/13	193	mortality	unknown	Bonaventure
02/25/14	Delaware Bay, DE	132879	PTT	Implant	1078-62751	A4Y	M	3,300	03/02/14	4	mortality	surgery	unknown
02/28/14	Delaware Bay, DE	132865	PTT	Implant	1078-62752	A4Y	M	3,050	04/30/15	425	unk/tag fail	battery	Funk
03/01/14	Chesapeake Bay, VA	132873	PTT	Implant	1078-62756	A4Y	F	3,400	03/04/15	367	mortality	unknown	Bonaventure
03/02/14	Chesapeake Bay, VA	132860	PTT	Implant	1078-62753	A4Y	M	3,690	12/01/14	273	unk/tag fail	battery	Bonaventure
03/04/14	Pamlico Sound, NC	132861	PTT	Implant	1108-07018	ASY	.	3,000	07/21/14	138	unk/tag fail	unknown	Bird Rocks
03/04/14	Chesapeake Bay, VA	132862	PTT	Implant	1078-62761	A4Y	F	3,000	03/06/14	1	mortality	surgery	unknown
03/04/14	Pamlico Sound, NC	132864	PTT	Implant	1108-07019	ASY	.	3,300	07/10/14	127	unk/tag fail	unknown	Bonaventure
03/04/14	Pamlico Sound, NC	132866	PTT	Implant	1108-07020	ASY	.	2,600	03/20/15	380	unk/tag fail	battery	Bonaventure
03/04/14	Chesapeake Bay, VA	132876	PTT	Implant	1078-62760	A4Y	M	3,250	04/13/15	404	unk/tag fail	battery	Bonaventure
03/08/14	Chesapeake Bay, VA	132863	PTT	Implant	1078-62764	ASY	F	3,300	02/07/15	422	unk/tag fail	battery	Bonaventure
03/08/14	Chesapeake Bay, VA	132867	PTT	Implant	1078-62763	A4Y	F	3,100	03/10/14	1	mortality	surgery	unknown
03/08/14	Chesapeake Bay, VA	132868	PTT	Implant	1078-62762	A4Y	F	3,500	03/09/14	0	unknown	unknown	unknown
03/08/14	Chesapeake Bay, VA	132869	PTT	Implant	1078-62758	A4Y	M	3,250	02/09/15	337	unk/tag fail	battery	Bonaventure
03/08/14	Pamlico Sound, NC	132870	PTT	Implant	1128-05501	ASY	.	3,650	04/17/15	404	unk/tag fail	battery	Bonaventure
03/08/14	Chesapeake Bay, VA	132871	PTT	Implant	1078-62757	A4Y	F	3,050	02/26/15	354	unk/tag fail	battery	Bonaventure
03/08/14	Chesapeake Bay, VA	132872	PTT	Implant	1078-62759	A4Y	F	3,250	04/24/15	410	unk/tag fail	battery	Bonaventure
03/08/14	Chesapeake Bay, VA	132874	PTT	Implant	1078-62755	A4Y	F	3,275	09/30/15	570	unk/tag fail	battery	Bonaventure
03/08/14	Pamlico Sound, NC	132877	PTT	Implant	1128-05502	ASY	.	2,900	12/03/14	269	unk/tag fail	unknown	Bonaventure
03/09/14	Chesapeake Bay, VA	132875	PTT	Implant	1078-62765	A4Y	F	3,450	03/10/14	0	unk/tag fail	unknown	unknown
03/09/14	Chesapeake Bay, VA	132878	PTT	Implant	1078-62764	A4Y	F	3,050	05/06/15	422	unk/tag fail	battery	Bonaventure
03/09/15	Chesapeake Bay, VA	146489	PTT	Implant	0968-87718	Ad	M	3,750	01/27/16	323	unk/tag fail	battery	Bonaventure
03/12/15	Chesapeake Bay, VA	146488	PTT	Implant	1078-62634	Ad	M	3,150	02/17/16	341	unk/tag fail	battery	Cape St. Mary’s

03/12/15	Chesapeake Bay, VA	146490	PTT	Implant	1078-62627	Ad	M	3,100	04/15/16	399	unk/tag fail	battery	Bonaventure
03/12/15	Chesapeake Bay, VA	146491	PTT	Implant	1078-62628	Ad	M	3,250	03/03/16	356	unk/tag fail	battery	Bonaventure
03/15/15	Chesapeake Bay, VA	146492	PTT	Implant	1078-62619	Ad	F	3,200	04/21/16	402	unk/tag fail	battery	Bonaventure
03/15/15	Chesapeake Bay, VA	146493	PTT	Implant	1078-62618	Ad	F	3,700	12/16/15	275	unk/tag fail	unknown	Bonaventure
03/15/15	Chesapeake Bay, VA	146506	PTT	Implant	1078-62617	Ad	M	3,200	04/29/15	40	mortality	unknown	Bonaventure
03/16/15	Chesapeake Bay, VA	146494	PTT	Implant	1078-62620	A4Y	F	3,500	03/24/16	373	unk/tag fail	battery	Bonaventure
03/16/15	Chesapeake Bay, VA	146495	PTT	Implant	1078-62629	A4Y	M	4,100	03/17/15	1	unk/tag fail	unknown	unknown
03/16/15	Chesapeake Bay, VA	146496	PTT	Implant	1078-62630	A4Y	F	3,300	03/16/16	365	unk/tag fail	battery	Bird Rocks
03/16/15	Chesapeake Bay, VA	146497	PTT	Implant	1078-62631	A4Y	M	3,800	03/25/16	374	unk/tag fail	battery	Bonaventure
03/16/15	Chesapeake Bay, VA	146499	PTT	Implant	1078-62632	A4Y	F	3,400	03/03/16	352	unk/tag fail	battery	Bonaventure
03/19/15	Chesapeake Bay, VA	146501	PTT	Implant	0968-87722	A4Y	M	3,700	12/04/15	259	unk/tag fail	battery	Bonaventure
03/19/15	Chesapeake Bay, VA	146503	PTT	Implant	0968-87723	A4Y	F	4,000	01/29/16	315	unk/tag fail	battery	Bonaventure
03/19/15	Chesapeake Bay, VA	146505	PTT	Implant	0968-87726	A4Y	F	4,100	01/15/16	301	unk/tag fail	battery	Cape St. Mary’s
03/19/15	Chesapeake Bay, VA	146507	PTT	Implant	0968-87730	A4Y	F	4,200	05/18/16	425	unk/tag fail	battery	Baccalieu
03/21/15	Chesapeake Bay, VA	146498	PTT	Implant	1058-00680	A4Y	M	4,000	03/28/16	372	unk/tag fail	battery	Bonaventure
03/21/15	Chesapeake Bay, VA	146500	PTT	Implant	1078-62635	A4Y	F	3,800	08/05/15	136	unk/tag fail	unknown	Bonaventure
03/21/15	Chesapeake Bay, VA	146502	PTT	Implant	1058-00679	A4Y	F	3,700	01/16/16	300	unk/tag fail	battery	Bird Rocks
03/21/15	Chesapeake Bay, VA	146504	PTT	Implant	0968-87729	A4Y	F	4,100	02/26/16	341	unk/tag fail	battery	Bonaventure

*indicates bird captured at the colony.

3. Occurrence patterns and migratory pathways of Red-throated Loons wintering in the offshore Mid-Atlantic U.S., 2012–2016.

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3.1 Summary

The Red-throated Loon (*Gavia stellata*) is listed by the U.S. Fish and Wildlife Service (USFWS) as a species of conservation concern throughout much of its Arctic breeding range and wintering grounds in the Atlantic Flyway. Approximately 70-100,000 Red-throated Loons are estimated to winter along the eastern U.S. coast, and the core of this wintering range is reported to occur in the mid-Atlantic region (New Jersey to North Carolina), with the largest concentrations reported off the coasts of Delaware and North Carolina. The offshore environment of the U.S. Mid-Atlantic region holds vast potential for wind energy development and most of the initial development interest and planning activity overlaps with the Red-throated Loon's core wintering range. Understanding the habitat and migratory corridors of seabirds within proposed wind energy areas is an important area of consideration when making informed siting decisions. Information is needed regarding seabird movement patterns and their timing of use within these zones in order to ensure that the potential adverse effects of development and operation of wind farms in the offshore environment are minimized. Red-throated Loons are an important study species for gathering information on potential risk associated with wind energy development in the mid-Atlantic region because: (1) they are considered vulnerable to collision mortality and displacement from offshore wind energy facilities, (2) a large proportion of their population winters in this region, and (3) they are designated a USFWS "species of conservation concern" on their wintering grounds along the Atlantic coast.

We initiated a satellite tracking study of Red-throated Loons captured at sea on their wintering grounds in the mid-Atlantic U.S. to determine the species' fine-scale occurrence and local movement patterns in the study area during winter and migration. In total, we captured 111 Red-throated Loons, of which 86 were released with PTTs during the winters of 2012 – 2015. Red-throated Loons in our satellite tracking study began arriving in the study area as early as November 18 and remained there until as late as May 28 each year. Winter use of the study area was most concentrated within the large bays of the mid-Atlantic study area – Delaware Bay, Chesapeake Bay, and Pamlico Sound. They also used smaller bays along the coastline between these large bays, but, to a much lesser degree. Core winter habitats were nearshore and comprised of areas with shallow, cold water and high primary productivity. Offshore use of the Atlantic Ocean was generally within 25 miles of the mainland with the most concentrated use occurring within 5 miles of shore. The results of our study indicated very little overlap during the winter period between birds we tagged and proposed offshore wind energy areas in the mid-Atlantic U.S. study area. However, overlap with wind energy areas was substantially greater in April and May when birds were departing the study area at the start of spring migration. Most Red-throated Loons in our study followed the Atlantic

coast northward, with major stopover sites including: Nantucket Shoals, the Gulf of St. Lawrence and St. Lawrence River. From here, birds fanned out across the Canadian Arctic arriving by mid-June at breeding locations, which included: mainland and Banks Island, Northwest Territories; mainland Nunavut and the Nunavut islands of the Canadian Arctic Archipelago; northwest Greenland; Manitoba; and northern Quebec. Red-throated Loons began moving south again in early September, with major fall migration stopovers including: Hudson Bay, James Bay, the Gulf of St. Lawrence, and the lower Great Lakes. Red-throated Loons returned to the mid-Atlantic study area at the end of the fall migration period beginning in mid-November and no later than mid-December each year.

3.2 Introduction

The offshore environment of the U.S. Mid-Atlantic region holds vast potential for wind energy development. An estimated 410 GW of wind energy are available for harnessing within 50 miles of shore between New York and Virginia, with approximately 25% occurring within State waters (up to three nautical miles from shore) and 75% occurring in Federal waters (3 to 50 nautical miles from shore; ELI 2013). Wind energy is associated with fewer environmental issues than fossil fuels; however, offshore wind energy development may pose multiple direct and indirect adverse effects to bird populations in the offshore environment (Fox et al. 2006). Hüppop et al. (2006) described those effects, which included: 1) habitat loss at the siting of offshore wind facilities, 2) disturbance due to noise, movement, and maintenance of the turbines, 3) increased energy consumption as a result of displacement from key foraging areas and flight pathways, and 4) collision mortality.

The scale and degree of these effects on seabirds varies considerably among sites, species, and even individuals within the same species (Drewitt and Langston 2006). This variation is influenced by location of the wind farm and its proximity to important habitats, the availability of alternative habitats, the number of birds reliant on the area, and their patterns of use according to season, time of day, and life cycle stage (e.g., breeding versus winter, diurnal versus nocturnal, and adult versus juvenile; Drewitt and Langston 2006). For those species that have exhibited noticeable sensitivity to offshore wind, contributing behavioral factors may include flight height, flight maneuverability, percentage of time spent flying (diurnal and nocturnal activity), susceptibility to disturbance from turbine, ship, and helicopter activity, and habitat specialization (Garthe and Hüppop 2004). Furthermore, the percentage of the biogeographic population occurring in the WEA development regions, adult survival rate, and conservation status all contribute to species' vulnerability to population level effects of offshore wind development (Garthe and Hüppop 2004).

Seabirds demonstrate a wide range of behavioral responses to offshore wind facilities, from complete avoidance to attraction, including many species in between showing relatively minimal responses (Dierschke et al. 2016). In European studies, several species have exhibited a behavioral response of avoiding offshore wind facilities, resulting in changes in the local distribution, abundance, and flight patterns of birds (Petersen et al. 2006). Red-throated Loons (*Gavia stellata*) and Arctic Loons (*G. arctica*), for example, were present in average densities prior to construction of a wind farm in coastal waters off Denmark. These species showed complete avoidance of the area during the construction phase and 3-yr post-construction period, with this avoidance effect extended to a distance of 2 km around the wind farm (Petersen et al. 2006). Robinson Willmott (2013) ranked the Red-throated Loon as highly sensitive to displacement and collision effects of proposed offshore wind energy development in the U.S. Atlantic Offshore Continental Shelf. Furthermore, multiple European studies have identified the Red-throated Loon as a species vulnerable to this type of disturbance or displacement (Halley and Hopshaug 2007, Percival 2014, Furness et al. 2013), and Garthe and Hüppop (2004) ranked Arctic Loons and Red-throated Loons highest among 26 seabird species wintering in German waters of the North Sea on their wind farm sensitivity index. Poor flight maneuverability, biogeographical population size, conservation status, high sensitivity to disturbance, and low habitat use flexibility were the greatest contributing factors to this ranking.

Approximately 70-100,000 Red-throated Loons are estimated to winter along the eastern U.S. coast (, and the core of this wintering range is reported to occur in the mid-Atlantic region (New Jersey to North Carolina), with the largest concentrations reported off the coasts of Delaware and North Carolina (Warden 2010). Although the development of offshore wind energy facilities are being considered for both U.S. coastlines and the Great Lakes, most of the initial development interest and planning activity overlaps with the Red-throated Loon's core wintering range, and is concentrated in the state and federal waters offshore of the mid-Atlantic region (Musial and Ram 2010). Red-throated Loons are an important study species for gathering information on potential risk associated with wind energy development in the mid-Atlantic region because: (1) they are considered vulnerable to collision mortality and displacement from offshore wind energy facilities (Garthe and Hüppop 2004, Furness et al. 2013, Robinson Willmott et al. 2013), (2) a large proportion of their population winters in this region (Forsell 1999, Root 1988), and (3) they are designated as a US Fish and Wildlife Service (USFWS) "species of conservation concern" on their wintering grounds along the Atlantic coast (USFWS 2008b). Bird species with a high proportion of their population occurring in offshore development areas, and those with high adult survival, are considered most vulnerable to population declines (Desholm 2009). Small changes in adult survival can result in significant population declines for species, such as loons, with low reproductive capacity and a slow maturation rate (Johnsgard 1987, Mitro et al. 2008). Furthermore, displacement from wintering habitat may result in increased energy expenditure and competition for food resources, which has the potential to affect overall population fitness through the reduction of annual adult survival (Fox et al. 2006).

In order to assess the effects of disturbance and the potential population impacts of offshore wind development on Red-throated Loons in the mid-Atlantic, basic information must be collected on their distribution and behavior, including flight pathways and timing of habitat use, within proposed WEAs. Multiple factors influence the distribution of a species during the non-breeding season, such as habitat quality, food supply, predation pressures, and behavioral characteristics (Newton 2008). Given the complexity of working in the marine environment, the great distances often covered by foraging individuals, and the challenges of detecting prey distributions at sea, limited information is available regarding the offshore distribution and ecology of many seabird species (Tremblay et al. 2009). Prior to the 1990s, obtaining such data on seabirds while at sea was limited to ship-based surveys that were restricted in the spatiotemporal extent of their observations. The advent of satellite tracking technology, however, has made it possible to track the movements of individual seabirds remotely (as reviewed by Wakefield et al. 2009). Distribution and abundance of marine birds in federal waters slated for offshore wind energy development have been the focus of aerial and boat-based survey efforts in recent years (Geo-Marine, Inc. 2010, NFSC and SFSC 2012, Veit and Manne 2015, Goyert et al. 2016). Few studies in North America, however, have tracked migratory and local within-season movements of individual birds to evaluate potential interactions with proposed offshore wind energy developments. Location data collected from satellite transmitters can also be used to estimate a probabilistic model of home range called the utilization distribution (UD; Worton 1989), which refers to the relative frequency distribution of an animal's occurrence in space and time (Van Winkle 1975). From here, the boundary of the animal's home range can be found by calculating the area that encompasses 95% of the volume of the distribution of space used (Anderson 1982, Laver and Kelly 2008). Identifying an animal's home range throughout the annual cycle or during specific periods, e.g., nonbreeding, provides information with direct management applications because it is the area containing all of the individual's ecological requirements (Seaman and Powell 1990). Optimal quality habitat is often indicated by longer periods of occupancy by individuals of a given species within a season and are used more consistently over time in comparison to low-quality habitats (Johnson 2007, Faaborg 2010). These spatially-explicit patterns of use can be related to the distribution of resources within the landscape in resource selection models to differentiate the characteristics that comprise high-quality versus low-quality habitats (Boyce and McDonald 1999, Manly et al. 2002).

Understanding the habitat and migratory corridors of seabirds within proposed WEAs is an important area of consideration when making informed siting decisions. Information is needed regarding seabird movement patterns and their timing of use within these zones in order to ensure that the potential adverse effects of development and operation of wind farms in the offshore environment are minimized. To that end, we initiated a satellite tracking study of Red-throated Loons captured at sea on their wintering grounds in the mid-Atlantic U.S. to determine the species' fine-scale occurrence and local movement patterns in the study area during winter and migration. Location data collected from satellite transmitters were used to estimate home-range size and other features of the utilization distribution, including core use areas, of wintering Red-throated Loons captured in the mid-Atlantic region in relation to proposed offshore WEAs.

3.3 Methods

3.3.1 Study Area

The priority study area included waters off the U.S. Atlantic coast from Long Island, NY, to the southern border of North Carolina (Figure 3-1); however, results include all US Atlantic Federal waters with potential offshore wind development. Three winter capture regions adjacent to the priority study area were selected: northern (New Jersey and Delaware), central (Maryland and Virginia), and southern (North Carolina). In 2012, capture efforts for Red-throated Loons were attempted on the following waterbodies: Pamlico Sound, NC; Chesapeake Bay, MD and VA; Chincoteague Bay, MD and VA; Assawoman Bay and Isle of Wight Bay, MD; Indian River Bay, DE; and Delaware Bay, DE and NJ. Capture efforts during the following three winters (2013–2015) were focused in areas where high concentrations of target species were observed during the pilot year field efforts, including: Pamlico Sound, offshore of Hatteras, NC; Chesapeake Bay, offshore of Cape Charles, VA; Delaware Bay, offshore of Lewes, DE; and the Atlantic Ocean, offshore of Cape Henlopen, DE and Chesapeake Bay Bridge area, VA.

3.3.2 Field Work

We captured Red-throated Loons on their wintering grounds in the mid-Atlantic study area and released them with abdominal-implanted Telonics IMPTAV-2640 (45 g) platform terminal satellite transmitters (PTTs). Capture efforts were conducted between late January and late March in each year using night-lighting techniques, i.e., birds were approached at night by boat with a spotlight and captured with a dip net. Loons were aged according to criteria established by Pyle (1997) and those determined to be "after third year" (ATY) and "after second year" (ASY) were considered primary candidates for PTT implantation. All captured birds were banded with USFWS aluminum bands. Individuals deemed fit for transmitter implantation surgery were administered 2 mg/kg of mild sedative, midazolam hydrochloride IM, prior to transfer to the surgery location to minimize stress related to capture and handling. Surgical implantations of intra-abdominal PTTs with external antenna were conducted by qualified veterinarians following techniques described in Chapter 5. Satellite transmitters weighed approximately 49 g and comprised < 4% of the average body mass of birds deployed. All field procedures, including surgical implantation of tags, were reviewed and approved under Institutional Animal Care and Use Committee number 2010-10 (USGS-PWRC).

Satellite transmitters were programmed with a duty cycle of 4 hours on and 13 hours off during the period of 1 November to 31 May, in order to detect fine-scale movement patterns when birds were expected to be on migration or wintering in the mid-Atlantic study area. Longer duty cycles were employed for the remainder of the year, when birds were outside of the study area, to maximize battery life: 2 hours on and 5 days off from 31 May to 31 August, and 4 hours on and 24 hours off from 31 August to 01 November. All location data collected within 14 days of deployment were excluded from analysis to reduce bias associated with surgery (Esler et al. 2000).

3.3.3 Satellite Telemetry

Telemetry data from PTTs are collected using the Argos system of satellites (http://www.argos-system.org/). A customized program written in the Python programming language (Python 2.7, http://www.python.org/) was created for downloading the last five days of data. Data for all active tags were retrieved by the program. Argos data from this study were stored or archived at several locations including MoveBank (www.movebank.org) and servers at the USGS Patuxent Wildlife Research Center. We compiled and analyzed archived data to remove redundant data and flag errant points using the Douglas Argos Filter (DAF, http://alaska.usgs.gov/science/biology/spatial/douglas.html). The DAF is a threshold filter that has several user-defined parameters to flag improbable locations in satellite tracking data (Douglas et al. 2012). The parameters are adjustable based on species' movement behaviors and the scale of the area under observation. With the DAF, data are retained if they pass (1) a spatial redundancy test and/or (2) a movement rate and turning angle test. Since bird data contain both short-distance, local movements and long-distance migratory events, we employed the hybrid filter of both the distance, angle, and rate (DAR) and minimum redundant distance (MRD) filters. This achieved the best of both filters and in practice has produced very clean data with few erroneous points. Using the DAF, we also identified the best representative point per duty cycle for each animal to reduce redundant daily positional information.

We compiled a database of deployment and life-history data for every PTT that was deployed during the project (2012 –2015). We stored data in a shared Google spreadsheet accessible by all project investigators. The database contained information about the PTT tags themselves as well as data on the capture and deployment history of all birds. Furthermore, "life-history period" start and end dates were noted for every animal, following species-specific life-stage criteria defined by the SDJV (Sea Duck Joint

Venture 2015). We identified the following life-history periods: breeding, molting, fall-staging, wintering, and spring-staging, for every year that the animal was alive and transmitted locations. We assigned final fate and the date for all non-active tags. We assessed sensor data for every tag to identify bird mortality (by internal body temperature sensor or mortality sensor) or battery/tag failure due to low transmitter voltage. We listed the day after last transmission as the last date of disposition for all birds with tags that stopped transmitting for either low voltage or unknown reasons. We calculated tag duration dates from the deployment start date and the final disposition date. The DAF filter works off of deployment dates to correctly parse PTT data. Since Argos-assigned PTT ID numbers can be recycled following a tag failure or mortality, it was necessary to re-run DAF filters once final dispositions were determined to allow the DAF filter to correctly parse the data. Maps presented in this report include DAF-filtered data through June 2016.

3.3.4 Data preparation for geospatial analysis and mapping

We wrote a custom script in R 3.3 (R Core Team, 2016) to automate preparation of data for geospatial analysis and mapping. This script used the DAF-filtered data and the corresponding life-history period data from the deployment database to assign points to seasonal period for each individual. We included in analyses no more than a single representative year of data over no more than two years per animal per season (e.g., winter, fall migration) to avoid biasing the analyses towards individuals with more years of data. Prior studies on ducks (Mulcahy and Esler 1999, Sexson et al. 2014) indicated that behavior may be most affected by tag implant surgery during the first 14 days after the procedure, resulting in movement patterns not representative of normal behavior during this initial period. In our study, most mortalities likely resulting from implantation occurred within 30 days of surgery. In almost every case, these birds displayed movement behaviors that deviated from that of birds that did not die within 30 days, such as travel far up rivers or onto land. Therefore, we omitted birds that transmitted < 30 days after release from analyses to reduce bias from birds that could have been negatively affected by transmitter implantation and handling. Overall this made up a very small fraction of our sample. We filtered the remaining data using the DAF assigned hybrid filter to remove points deemed to be in error, keeping the remaining locations for analyses. We assigned mean errors (Douglas et al. 2012) to location classes (Table 3-1) for use in dynamic Brownian bridge movement analyses which includes location errors in analyses (Kranstauber et al. 2012). We used the 95th error percentiles for data using the parameter MAXREDUN = 15 km in the DAF filter. While this is a liberal error assignment for locations, in practice the models are robust to changes in such values.

3.3.5 Dynamic Brownian Bridge Movement Model

We determined sample population level utilization distributions for each species by calculating individual level dynamic Brownian bridge movement model (dbbmm) surfaces (Kranstauber et al., 2012) using package Move for R (Kranstauber and Smolla, 2016). Most birds were captured and tagged in late winter, and PTT battery life averaged less than or equal to one year. Therefore, most tags lasted only part way through winter of the second year post-tagging. Since maximizing understanding of winter movements was a major focus of the study, we calculated separate dbbmm surfaces for two winters with at least five days of data and combined these into a weighted mean surface for each animal (as a percentage of the total number of days represented in the surface) with a minimum 30 total combined days of data. We removed any temporal overlap between these datasets (e.g., March 1-15 is represented only in one surface) to minimize biases introduced by overlapping temporal coverage. We used this method of combining multiple seasons for the migration periods as well, but relaxed the requirements for days of data, requiring only five days per year and seven total days per period because migration often occurred over a much shorter time period. Utilization contour levels of 50, 75, and 95% were calculated for the mean utilization distribution (UD) surface. The final UD was cropped to the 95% contour for mapping and further analyses. Individual movement models were also saved for analyses of individual home range use and movement.

3.3.6 Use of Lease Areas and Wind Energy Areas

We calculated use of WEAs and Lease Areas by tagged loons in two ways: 1) as a percentage of overlap of each WEA and Lease Area by the 50% (core use) and 95% (home range) UD areas, and 2) as a percentage of the total 50% (core use) and 95% (home range) UD seasonal distributions area overlapped by the WEA and/or Lease Area. Spatial overlap was determined in R version 3.3.1 (R Core Team 2016) using package raster (Hijmans 2016). Low sample sizes limited our analysis to the aggregate distribution of individuals across all years of the study and available data. Overlap of Lease Areas and/or WEAs and the seasonal distribution of our sample represented a probability (Kie et al 2010) that individuals used the areas during the season, and would have been exposed if turbines were present in those areas, and the % of the entire area that individuals used that was occupied by a WEA and/or Lease Area.

3.3.7 Arrival and Departure into and out of the Study Area by Sex

We plotted the latitudes of all tagged individuals by date to show latitudinal progression from wintering grounds to breeding grounds, and back. We examined differences among sexes in our plots and aggregated data into 5-day intervals and calculated mean (± standard deviation) latitudes for each interval. The study area was drawn in the figure as a dark gray box to highlight use of the BOEM study area. We generated histograms of the proportion of all animals with active tags south of the northernmost boundary of the BOEM study area (41^{o} N latitude). We used proportion instead of raw counts because the number of active tags was not consistent over the year and resulted in graphs biased by the number of active tags in the study area. We determined the date of first arrival in fall south of the northern boundary and the last departure in spring north of the study area. We generated histograms for combined and separate sexes.

3.3.8 Habitat Selection

The evaluation of resource preference pertains to the measurement of habitat components an animal *uses* in its environment compared to what is *available* during that same period of time (Manly et al. 2002). Johnson (1980) identified four hierarchical scales at which animals select resources: (1) first order – the geographic range of the species; (2) second order – the home range of an individual; (3) third order – the habitats used by an individual within its home range; and (4) the individuals resources selected within each habitat. Our first objective was to identify habitat characteristics of the composite winter home range of all individuals—second order resource selection. We defined *used* as the pooled telemetry point locations that fell within the 0.95 isopleth of the dbbmm composite winter UD. Used resources are a subset of available resources, and a key factor in resource selection studies is determining the extent of the area that will be included for sampling *available* resources (Buskirk and Millspaugh 2006). We selected the Mid-Atlantic Bight as the extent of habitat available for second order resource selection of the wintering home range. The Mid-Atlantic Bight extends from Nantucket Shoals off southern New England southward to Cape Hatteras off North Carolina. It is bordered by the U.S. coastline on the west and the continental shelf-break on the east. Available points consisted of a random selection of points generated within boundaries of the Mid-Atlantic Bight that was equal to the total number of *used* points (n = 26,388).

Our second objective was to determine the habitat characteristics of the core use areas within the composite winter home range – third-order resource selection. We used the pooled telemetry points that fell within the 0.50 isopleth for the *used* or *core use areas*. We used a custom script in R version 3.3 (R Core Team, 2016) to match each used point in the core use area of each animal to two random *available* points randomly generated within the individual's home range. The dates for each matched core-use point (n = 8,796) were used for assigning temporally-explicit covariates (e.g., SST, chlor-a) to the random points (n = 17,592). The selection of telemetry point locations within the 0.50 isopleth for comparison of the habitat characteristics of those points to points generated within the individual's 0.95 utilization distribution is described in greater detail under sampling protocol-A in Manly 2002.

Habitat characteristics were chosen based on *a priori* knowledge of marine habitat and availability of spatial data within the study area, and included water depth (m), distance to shore (km), long-term (10-yr winter mean) and seasonal mean sea surface temperature (°C), long-term (10-yr winter mean) and seasonal chlorophyll *a* (mg/m^3), long-term (6-yr winter mean) and seasonal sea surface salinity (practical salinity units, PSU), and sediment grain size (mm). We measured water depth using the NOAA National Geophysical Data Center 3 arc-second Coastal Relief Model for the United States (NOAA 2014a). To estimate distance from shore, we calculated the Euclidean distance between Red-throated Loon locations and the nearest segment of the NOAA Medium Resolution Digital Vector Shoreline (1:70,000) using the Near tool in Arcmap 10.2.2 (ESRI, Redlands, CA; NOAA 2014b). Sediment grain size categories were also obtained from the Nature Conservancy's Northwest Atlantic Marine Ecoregional Assessment data portal. Size categories were grouped by the Nature Conservancy according to correlations with benthic habitat communities, and are not necessarily related to Red-throated Loon habitat requirements. For the dynamic variables with a temporal component, we used Marine Geospatial Ecology Tools to retrieve values for each location based on the date of transmission (Roberts et al. 2010). We used smoothed mean monthly Sea Surface Salinity (SSS; PSU) and Sea Surface Temperature (SST; °C) estimates based on optimal interpolation of data derived from high resolution satellite imagery and floating buoys (Stark et al. 2007). These data were produced by the UK Met Office on a global scale at a spatial resolution of 0.54 degrees latitude and longitude. To measure ocean productivity, we obtained monthly estimates of chlorophyll *a* concentration (mg/m^3) produced by the NASA Goddard Space Flight Center's Ocean Data Processing System. These data had a spatial resolution of 4 km and were derived from radiometric measurements of chlorophyll fluorescence made by the Aqua sensor aboard the MODIS satellite system (Mueller et al. 2003). Raster and polygon data layers of previously described habitat measurements and animal location data layers were analyzed in ArcGIS 10.2.2. using the WGS 84 spatial projection.

We used the R package, *lme4*, to create generalized linear mixed models, in which animal ID was included as a random effect to allow the intercept to differ between individuals, to explore habitat covariate effects on used versus available locations (Bates et al. 2015, R Core Team 2016). Development of models was exploratory, but, based on *a priori* knowledge of seabird habitat, we predicted that used locations would be related to nine habitat covariates: depth, distance to shore, long-term and seasonal chlorophyll *a*, long-term and seasonal sea surface temperature (SST), long-term and seasonal sea surface salinity (SSS), and sediment grain size. Point locations from the winter dbbmm analysis were included in the resource selection models only if complete coverage was available for all the measured habitat characteristics described above. Culling point locations with incomplete coverage, however, generally resulted in the inclusion of fewer individuals in the resource selection analyses (*n* = 39 for second order and *n* = 41 for third order) than the number included in the winter dbbmm analyses (*n* = 46). The difference in sample sizes between the second order and third order analyses is due to the difference in habitat data coverage for the spatial areas under consideration in each analysis. Specifically, the “available” data points in the third order resource selection analysis extend throughout the winter home range while the “available” points in the second order resource selection analysis extend throughout the entire Middle Atlantic Bight. This approach ensured consistency among data sets during the model selection process (described below) for each of the resource selection analysis efforts. Correlations between pairs of continuous habitat variables were quantified using a Pearson product-moment correlation matrix. Multicollinearity among covariates was assessed by calculating variance inflation factors (VIF). Covariates with pairwise correlations of < 0.60 and VIF values of < 2.3 were retained as variables in the modeling process. Correlation and VIF results indicated multicollinearity among the following variables: (1) long-term SST and seasonal SST, (2) long-term to seasonal SSS, and (3) long-term to season chlorophyll *a* concentration.

The data were fitted to each singular term to determine the covariate best suited for including in the suite of candidate resource selection models. Results indicated that long-term mean winter SST and chlorophyll *a* were stronger predictors of use for Red-throated Loons compared to mean monthly SST and chlorophyll *a*. Conversely, mean monthly SSS was a stronger predictor of use compared to long-term SSS. Correlation and VIF values of the remaining variables were all within the above stated limits.

We used a nested model approach and candidate models were ranked with Akaike Information Criterion adjusted for small sample size (AIC_c). The model with the lowest AIC_c, and those having $\Delta AIC_c \leq 2$ had the most statistical support, values between 4 and 7 had considerably less support, and those > 10 had virtually no support (Burnham and Anderson 2002). The Akaike weight was also considered when determining the relative amount of statistical support for each model. The importance of the individual explanatory variables in the top nested model were assessed by dropping one term in turn and further comparing AIC values to determine if any variables could be dropped from the model. We estimated confidence intervals for the best-fit population-level RSF model using model-based semiparametric bootstrapping (1,000 iterations) calculated from the bootMer function within the lme4 package.

3.4 Results

3.4.1 Tagging Summary

We captured 111 Red-throated Loons, of which 86 were released with PTTs during the winters of 2012 (*n* = 17), 2013 (*n* = 26), 2014 (*n* = 23), and 2015 (*n* = 20). Of the 86 birds released with PTTs, there were 51 females, 28 males, and 7 of unknown sex. Body mass of females ranged from 1,400-2,150 g and 1,700-2,600 g for males. In total, 24 died within the 14-day post-release period, which has been reported as the time period in which mortality can confidently be attributed to surgery for sea ducks (Mulcahy and Esler 1999). This corresponds with surgery-related mortality rates of 41% (*n* = 7) for 2012, 31% (*n* = 8) for 2013, 17% (*n* = 4) for 2014, and 25% (*n* = 5) for the 2015 season. Six additional Red-throated Loon mortalities occurred after the 14-day post-surgery period but before the 30 day cutoff we established as the minimum number days after release a bird must be active in order to be included in the analysis, of which 50 birds met those requirements. For the mortalities that occurred before 30 days but after 14 days, 4 were in 2013 and 2 were in 2014. Another 10 mortalities occurred after the 30 day cutoff, either during migration or on the breeding grounds; there were 3 in 2012, 2 in 2013, 1 in 2014, and 4 in 2015. Satellite transmitters on birds that did not suffer mortality during the life of the transmitter had an average duration of 370 ± 74 days, with a maximum duration of 544 days and minimum of 100 days.

3.4.2 Occurrence and Movement in U.S. Offshore Waters

3.4.2.1 Winter Use of Study Area

Red-throated Loons in our satellite tracking study began arriving in the study area as early as November 18 and remained there until as late as May 12 each year (Figure 3-2). Females we tracked typically arrived in the study before males and stayed longer. Winter use of the study area was most concentrated within the large bays of the mid-Atlantic study area – Delaware Bay, Chesapeake Bay, and Pamlico Sound (Figure 3-3). They also used smaller bays along the coastline between these large bays, but, to a much lesser degree. Offshore use of the Atlantic Ocean was generally within 25 miles of the mainland with the most concentrated use occurring within 5 miles of shore. The mean winter home range (95% UD) included all of Delaware Bay; however, the area of core use (50% UD) was concentrated along the Delaware side of the bay south of Dover to Cape Henlopen. Another smaller core use area was located on the northern side of the bay along New Jersey’s Fortescue Fish and Wildlife Management Area. The mouth of Delaware Bay was also part of the winter home range extending south along the Delaware Atlantic coastline to Rehoboth Beach, including a small core use in Indian River Bay. Only a very small percentage of WEAs and Lease Areas overlapped with loon winter home range (< 0.3%; Table 3-2), and did not overlap at all with core use (Table 3-3).

The winter home range also included Chesapeake Bay, extending from Annapolis south to the Bay Bridge at the mouth, with smaller core use areas just offshore of Annapolis and also in the northern and southern sections of Tangier Sound. The largest area of core use in Chesapeake Bay was along Virginia’s western shore of the southern Delmarva Peninsula, which extended south across the interior mouth of the bay to Norfolk, VA. Several large tributaries of Chesapeake Bay also comprised core use areas of Red-throated Loons, including the Potomac, Rappahannock, and James rivers.

The largest section of the home range occurring in the Atlantic Ocean was along the coastline extending from the Chesapeake Bay Bridge to the southern end of Ocracoke Island in the Outer Banks, North Carolina. The region along coastal Hatteras Island in the Outer Banks and extending approximately 10 miles offshore comprised the southernmost core use area in the Atlantic. The majority of Pamlico Sound was an area of core use, with the exception of the northern shoreline of the waterbody, which was, however, part of the home range along with two major tributaries, the Pamlico and Neuse Rivers.

3.4.2.2 Winter Movements in the Study Area

We observed local movements in winter within the bays where individuals were captured and released, as well as larger scale movements along the coast. Many Red-throated Loons continuously moved south throughout winter; for example, individuals tagged in Delaware Bay in late January/early February often slowly traveled south along the Delmarva Atlantic coastline to the mouth of the Chesapeake Bay in

February, and then moved south again along the Virginia and North Carolina Atlantic coastline to Pamlico Sound in March. These birds often stayed here for several weeks before beginning their spring migration north. The same pattern of moving south toward Pamlico Sound in late February was often observed for birds captured in southern Chesapeake Bay. Figure 3-4 supports these observations and shows a small yet gradual decrease in latitude that occurs within the study area over the course of the winter season. Indeed, most birds did not reach the lowest latitude in the home range – Pamlico Sound, NC – until late February, where they remained until at least mid-March. We did, however, find large numbers of Red-throated Loons in Pamlico Sound in late January/early February that remained within the waterbody until spring. Furthermore, some individuals tagged in Pamlico Sound returned here in early winter the following season, bypassing all the more northern locations in the study area.

3.4.2.3 Migratory use of study area and migratory patterns

In late March, loons in Pamlico Sound typically moved offshore to the core use area in the Atlantic off of Hatteras Island signaling the start of the spring migration period. There was a small degree of overlap (8%) between the North Carolina OCS-A 0508 Lease Area and spring migration home range (95% UD) and (Table 3-2). Males typically began moving north through the study area prior to females beginning in early April each year (Figure 3-4). Greater overlap was observed with the Virginia OCS-A 0483 Lease Area (32%) during this time period of early spring migration (Table 3-2). There was complete overlap (100%) of the Maryland, Delaware, and New Jersey WEAs and Lease Areas with spring home range (95% UD) as loons traveled northward toward Raritan Bay, New Jersey, lower New York Harbor, and the Long Island Atlantic coast during the early stages of spring migration in May each year (Figure 3-5). Narragansett Bay, RI, Long Island Sound, and Cape Cod Bay, MA, were major stopover sites in the northern part of the study area; Nantucket Sound and Shoals, though, were by far the most heavily used stopover in this region, where birds typically spent up to two weeks before continuing north (Figure 3-6). As a result, there was also complete overlap (100%) of the Massachusetts and Rhode Island WEAs and Lease Areas with home range during May each year (Table 3-2). Primarily only the Cape Wind Lease Area (MA OCS-A 0478) overlapped with core use (50% UD) within the study area (54%; Table 3-3).

Red-throated Loons arrived in the mid-Atlantic study area at the end of the fall migration period beginning in mid-November and no later than mid-December each year. They did not spend as much time in southern New England during the fall migration compared to spring, and, as such the degree of overlap with WEAs was much less for this time period (Table 3-2). The Cape Wind lease area, however, still overlapped completely with the fall migration 95% UD. Additionally, the Massachusetts OCS-A lease areas 0500 and 0501, as well as the Massachusetts WEA overlapped with the 95% UD at proportions of 43%, 39%, and 41%, respectively. Further south in the study area, 29% of the Delaware lease area overlapped with the fall migration 95% UD, as did WEAs in Maryland, New York, and Rhode Island to much lesser extents (Table 3-2). No other lease areas along the Atlantic U.S. overlapped with the fall migration 95% UD and no lease areas in any part of the study overlapped with the fall migration 50% UD.

Despite the relatively large amount of overlap of WEAs and Lease Areas with home range during spring migration, this overlap represented only a very small percentage of the total area of home ranges in the Mid-Atlantic area (< 1% Table 3-2). Overlap made up even a smaller percentage home range during fall migration (< 0.25% Table 3-2). The minimal overlap of loon core use area during spring migration accounted for < 0.3% of the total core use area (Table 3-3). This indicates that current WEAs and Lease Areas have a relatively small footprint compared with the entire UDs of loons.

3.4.3 Factors influencing Occurrence

3.4.3.1 Home Range Area Selection

The top supported second order resource selection model predicting Red-throated Loon selection of winter home range areas within the Mid-Atlantic Bight (MAB) included distance from shore, long-term chlorophyll *a*, long-term sea surface temperature, long-term sea surface salinity, and sediment grain size (Table 3-4). Water depth was an exceptionally strong predictor of Red-throated Loon home range selection within the MAB; however, quasi-complete separation among these predictor variables caused warning messages in the model output. Specifically, all points in water depths greater than 282 m were in the randomly generated *available* point category ("0") and all of those in less than 282 m were in the home range point category ("1"). There was some degree of overlap for the two outcomes where water depth was < 282 m, hence the "quasi-complete" designation rather than "complete" separation. But, for points greater than 282 m, water depth perfectly predicted the outcome of a response of "0". Maximum likelihood estimation does not exist mathematically for such situations, resulting in biased coefficients and large standard errors. One option is to apply Firth's method to candidate models, which maximizes a penalized likelihood function to adjust for bias in the estimates resulting from quasi- or complete separation (Firth 1993). Using this method on the Red-throated Loon data resulted in very large confidence intervals for our coefficient estimates, and, so we opted to remove the offending variable from the model. Water depth and distance from shore, however, were co-linear (0.68) among Red-throated Loon locations; therefore, we surmised that distance from shore would also adequately represent water depth in our models.

The scaled beta coefficients, which allow for direct comparison of the strength of the effect of covariates with different measurement units, confirmed that distance from shore had the strongest effect on the selection of a winter home range relative to the other variables in the model (Table 3-6; Figure 3-7). Although, distance from shore did not return complete or quasi-separation warning messages, the odds ratio of zero indicates some degree of separation in our model for this variable. Odds can range from zero (event will never happen) to infinity (event will most certainly happen). The odds ratios in Table 3-6 represent the ratio of the odds of a point location being in the Red-throated Loon winter home range area to the odds of a point location not being in the home range. The odds of a location not being in the winter home range as distance from shore increases is essentially zero in our model due to infinity being the denominator of that ratio. Mean distance from shore in the home range was 8.96 ± 5.81 km compared to 76.88 ± 52.45 km for *available* points randomly generated throughout the Mid-Atlantic Bight (Table 3-6). Long-term mean winter SST (SST10) had a smaller effect on home range selection compared to distance from shore, but, was still quite influential on home range selection (Table 3-5). Each 1 °C increase in SST10 was associated with a 225% increase in home range area selection within the Mid-Atlantic Bight (Table 3-5; Figure 3-8). SST10 in the winter home range ranged from 4.09 - 19.83 °C with a mean of 8.26 °C (Table 3-6). The Red-throated Loon winter home range was associated with higher long-term mean winter chlorophyll *a* concentrations (CHLOR10; $\bar{x}$ = 6.58 ± 4.54 mg/m^3) compared to other areas of the Mid-Atlantic Bight ($\bar{x}$ = 1.93 ± 2.24 mg/m^3; Table 3-6). Each 1 mg/m^3 increase in CHLOR10 was associated with 109% increase home range area selection within the Mid-Atlantic Bight (Table 3-5;

Figure 3-9). Conversely, the home range was associated with lower sea surface salinity (PSU; SSS6) compared to more offshore areas of the Mid-Atlantic Bight, with each 1 PSU increase in SSS6 associated with a 40% decrease in the probability of selection (Table 3-5, Figure 3-10). Each of the sand sediment grain size categories and gravel were associated with increased probability of use relative to the silt/mud category (Table 3-5). The sand grain size of 0.17 – 0.35 mm, however, had the greatest frequency of occurrence at Red-throated Loon locations within the winter home area (Table 3-7).

3.4.3.2 Core Use Area Selection

The top supported third order resource selection model predicting Red-throated Loon winter core use site selection within their home ranges included a random effect of animal ID, water depth, long-term mean winter chlorophyll *a*, seasonal sea surface salinity (PSU), and distance from shore (Table 3-8). The intercept is -1.99 with a variance of 2.99 associated with the random effect for animal; the intraclass correlation among habitat characteristics found at locations of the same individual was 0.48 (Table 3-9). Probability of selection for core use areas decreased 26% with each one meter increase in water depth (Table 3-9; Figure 3-11). Mean water depths averaged $\bar{x}$ = 12.09 ± 5.92 m in core use areas, compared to $\bar{x}$ = 16.11 ± 153.42 m for the home range (Table 3-10). Long-term mean winter chlorophyll *a* concentrations had a positive effect on core use site selection with each 1 mg/m^3 increase associated with a 25% increase in probability of core use site selection (core use areas: $\bar{x}$= 7.89 ± 4.13 (mg/m^3); home range: $\bar{x}$ = 6.31 ± 4.45 (mg/m^3; Figure 3-12, Tables 3-9 and 3-10). Each 1 PSU increase in seasonal sea surface salinity was associated with a 20% decrease in the probability of core use site selection (Table 3-9, Figure 3-13). Mean sea surface salinity averaged $\bar{x}$ = 30.76 ± 4.54 PSU in core use areas compared to $\bar{x}$ = 31.94 ± 3.60 PSU in rest of the winter home range (Table 3-10). Increasing distance from shore also had a negative effect of the probability of core use area selection. Each 1 km increase in distance from shore was associated with a 58% decrease in core use area selection (Table 3-9, Figure 3-14). Core use areas averaged 6.72 ±3.57 km from shore, while the remainder of the home range averaged 10.01 ± 6.10 km (Table 3-10).

3.4.4 Migratory Connectivity and Breeding areas

Red-throated Loons in spring migration left southern New England in mid-May and moved quickly through the Gulf of Maine to the Bay of Fundy, and on to another critical stopover area, the Gulf of St. Lawrence and St. Lawrence River (Figure 3-15). Birds typically spent 3 to 4 weeks in this region. In early June, males began moving northward, just prior to females, fanning out across the Canadian Arctic arriving by mid-June at breeding locations, which included: mainland and Banks Island, Northwest Territories; mainland Nunavut and the Nunavut islands of the Canadian Arctic Archipelago; northwest Greenland; Manitoba; and northern Quebec.

Red-throated Loons remained on breeding grounds until late August/early September, at which point they began the annual southward fall migration; although, most birds stayed at northern latitudes, such as the Canada's Hudson and Ungava Bays, for periods up to 8 weeks before continuing south. While in Hudson Bay, loons slowly moved south along the western shoreline, presumably taking advantage of the counterclockwise sea surface currents of the bay to assist their journey (Figure 3-16). In late October, birds typically moved southward from lower Hudson Bay/James Bay to either the Lower Great Lakes (Ontario and Erie) or the St. Lawrence River. From here, loons returned to the study area for winter by either using an overland route from the Lower Great Lakes to Delaware Bay or moving south along the east coast using the same route they took north, but at a much faster rate of several days compared to several weeks.

3.5 Discussion

The identification of priority habitats for seabirds and the development of effective mitigation strategies for reducing the adverse effects of offshore wind farms require baseline information on their distribution, abundance, and patterns of use (Winiarski et al. 2014). Species vulnerability to the hazards associated with wind energy development in the offshore environment, i.e., collision mortality and displacement, is largely shaped by the scale and degree of their exposure. The results of our study indicated very little overlap between Red-throated Loons we tracked over the course of four winter periods (2012 – 2015) and proposed offshore wind energy areas in the mid-Atlantic U.S. study area. They typically arrived in the mid-Atlantic study area at the end of the fall migration period beginning in mid-November and no later than mid-December each year. These arrival dates are in keeping with observations from the Cape May Bird Observatory's annual coastal count of birds passing southern New Jersey, which indicated that the majority of the Red-throated Loons (*n* = 57,679) wintering in the mid-Atlantic arrive between 15 October and 15 December (Forsell 1999). We observed seasonal variation in the use of the study area; the northern half had greatest use early to mid-winter while the southern half was used by the largest number of birds mid to late winter. Certain areas, however, such as the mouth of Chesapeake Bay and Pamlico Sound showed consistent use throughout all winter months each year compared to other parts of the study area. These results indicated the importance of those sites as optimal quality habitat to wintering Red-throated Loons. Similarly, the offshore waters of Cape Hatteras National Seashore were heavily used by most of the birds we tracked each March when they were presumably keying in on some important food resource to fuel the first stages of spring migration.

Red-throated Loons are pursuit divers that dive from the surface to pursue their small forage fish prey (Eriksson 1985, Guse et al. 2009). Dierschke et al. (2017) suggested that Red-throated Loons feed on schooling fish ranging from 20-30 g in body mass. No information is available regarding the winter diet of Red-throated Loons in North America; however, herring (*Clupea harengus*), sprat (*Sprattus sprattus*), and sandeels (*Ammodytes marinus*) have been identified as potential prey for Red-throated Loon wintering in the Europe's North and Baltic Seas (Cramp and Simmons 1977, Guse et al. 2009). The birds we tracked exhibited a strictly coastal distribution and water depth associated with use was shallow; half the core use locations occurred in depths of less than 11 m. Warden (2010) found that the majority of Red-throated Loons taken as bycatch in mid-Atlantic waters occurred in waters depths less than 8 m (84%), while just 16% occurred at depths of 8 – 12 m, and none were observed in water ≥ 12 m. This is similar to winter habitat used by Red-throated Loons in Europe, which has been described as nearshore, sandy, shallow marine waters (Guse et al. 2009, O'Brien et al. 2008). Among Red-throated Loons in the Baltic Sea, the greatest densities of birds were observed within an area with a water depth zone of 5 to 30 m (Skov et al. 2011). Loons in our sample utilized tidal rivers, bays, and ocean habitats. Seventy-five % of core use locations occurred within five miles of shore and probability of use decreased rapidly with increasing distance from shore. In the North Sea, loons were observed to adhere to a strictly coastal occurrence and abundance decreased rapidly with increasing distance from shore (Busch et al. 2013). In the mid-Atlantic U.S., Goyert et al. (2016) found that abundance of Red-throated Loons was greatest in the nearshore waters between Cape Henlopen, DE, and Virginia Beach, VA, and at the mouths of

Delaware and Chesapeake Bays. Heaviest use of the Atlantic coastline in our study was observed around the mouth of the Chesapeake Bay, south to the Virginia/North Carolina border, and along the Cape Hatteras National Seashore, NC. Use of the study area, however, was most concentrated in the large bays of the study area, including the Delaware side of Delaware Bay, southern Chesapeake Bay, VA, and Pamlico Sound, NC. Goyert et al. (2016) determined that loon use of the mouths of Delaware and Chesapeake Bay was related to salinity fronts and primary productivity. Resource selection analysis of the habitat used by the loons we tracked also indicated seasonal salinity and long-term chlorophyll *a* as important factors driving the selection of core use areas. Winiarski et al. (2013) found a similar relationship between Common Loon distribution and abundance and areas of high long-term chlorophyll in coastal southern New England, concluding that locations with higher primary productivity would also have high biomasses of forage fish.

The start of spring migration when satellite-tagged Red-throated Loons moved north through the study area was the period of greatest overlap of WEAs and Lease Areas with loon distribution in the region. Migration trajectories through the Maryland, Delaware, New Jersey, and New York lease areas during the month of April raised the potential for exposure to the effects of wind energy development in the mid-Atlantic. This finding is not surprising given that wind farm locations require high wind yields, and, this characteristic is also common of migratory corridors, particularly along the U.S. Atlantic Outer Continental Shelf (Schuster et al. 2015). Use of the space in and around these Lease Areas, however, was greater during the spring migration compared to fall migration. This seasonal difference was likely related to more birds using an overland migration strategy in the fall, pushing through the Great Lakes directly to Delaware Bay and Chesapeake Bay, whereas spring migration typically involved movement of more individuals along the Atlantic coastline.

Overall, usage of any single WEA represented a very small fraction of the total of any seasonal distribution of loon examined in this report (< 0.3% of total home range - 95% UD). Even overlap of all combined WEAs and Lease Areas with loon distributions made up a small portion of the total for the season with highest overlap (< 1% for home range - 95% UD). It is important to note, however, that the distributions derived from this study only represent seasonal use by those sampled individuals during the years of our study. Estimates of spatial distribution do not account for inter-annual variability in distribution, differences in use among age-class or sexes, or any of the complex interactions among these variables for the Red-throated Loon population as a whole. Furthermore, the observed percentage of WEAs and Lease Areas overlapping UDs within a season may not fully capture how birds are using the space within that entire time period. For example, although a WEA may represent < 1% of the home range area, this does not necessarily indicate the rate at which birds transited the WEA, or the proportion of time spent within that WEA. The dbbmm models provide information about the potential for exposure at WEAs and Lease Areas, and do not consider the influence of additional factors contributing to risk, such as flight height and behavior.

Red-throated Loons that wintered in English waters were classified with a vulnerability risk rating of “moderate” for collision mortality and “high” for displacement by offshore wind farms (Bradbury et al. 2014). Flight height and flight maneuverability were among the factors that contributed to collision risk, and, this risk was expected greatest where turbines overlapped with migratory flyways or local flight paths (Drewitt and Langston 2006). Arctic Loons and Red-throated Loons ranked lowest relative to other seabird species in Europe in their ability to avoid collision with wind farms at sea (Garthe and Hüppop 2004). The likelihood of such interactions, though, is predicated on the probability of loons using the airspace within the rotor swept zone of wind farms. Flight heights of Red-throated Loons that wintered in Europe were typically 5 – 10 m above sea level (asl; Garthe and Hüppop 2004), and, time spent in flight at turbine blade height (~20 - 150 m asl) was estimated to have occurred just 5% of the time (Bradbury et al. 2014). Dierschke et al.'s (2016) review of the literature noted strong avoidance behavior, with zero observations of loons between turbines at the most studied wind farms in Europe, and only incidental records at other sites. In these cases, wind farms were barriers resulting in displacement of species that exhibited such "macro-avoidance" behavior, whereby flight paths were modified with vertical or horizontal movements in the effort to avoid the area (Drewitt and Langston 2006, Schuster et al. 2015).

Increased energy expenditure associated with these deviations from normal routes has raised concern for the potential of population-level impacts of displacement. Energetic costs of flight vary accordingly with species morphology and mode of flight – flapping versus gliding. Members of the loon family (Gaviidae) have narrow, heavily-cambered wings that are quite short for their body size, which results in high-wing loading ratios, and, subsequent high physiological costs associated with flapping flight (Johnsgard 1987, Hill et al. 2008). Masden et al. (2010) modeled differences in energetic costs associated with additional foraging distances across breeding seabird species with contrasting morphologies. Results indicated that species with high wing-loading required the greatest additional energy, and, while the costs of avoiding one farm on a daily basis may be inconsequential, the same cannot be assumed as the number of wind farms increases. Our results indicated minimal displacement from daily foraging locations; however, trajectories of loons through lease areas during spring migration suggest that flight path detours may be necessary for at least some proportion of the population if wind farms are developed at these sites. Fox et al. (2006) stated that the energetic costs of incurring additional travel distances of 20 km or less were insignificant for migrating birds traversing several hundred kilometers. They concluded though that, at greater spatial scales, the cumulative energetic cost of avoiding wind farm structures within migration corridors needed to be incorporated into annual energy budgets to assess its significance in terms of fitness costs.

Busch and Garthe (2016) identified two determinants to consider when assessing the displacement effects of offshore wind: 1) the proportion of the population relocating, i.e., relative strength of effect, and 2) the influence on survival rates and overall fitness, i.e., ecological consequences. Indeed, physical condition of an individual on the wintering grounds can result in carryover effects in subsequent seasons, including the timing or capacity to migrate, breed, or survive (Marra et al. 1998, Studds and Marra 2005). Small changes in adult survival can result in significant population declines for loons, which are long-lived, have low reproductive capacity, and a slow maturation rate (Mitro et al. 2008, Grear et al. 2009). Significant stressors linked with loon mortality already exist on the wintering grounds, including inclement weather, energetic costs of migration and feather replacement during the annual molt (Forrester 1997), exposure to contaminants, such as mercury and PCBs (Eriksson et al. 1992, Schmutz et al. 2009), oil spills (Sperduto et al. 2003), and as bycatch in fishing nets (Warden 2010, Zydelis et al. 2013).

Data related to population estimates and trends of Red-throated Loons are limited; some populations are considered stable, while others appear to have declined, and the trajectories of many other populations are unknown. Dickson and Beaubier (2011) detected very little change in the number of breeding pairs in the

Canadian Beaufort Sea region between the 1985-1989 and 2007-2008 survey periods. The Alaska-Yukon Waterfowl Breeding Population Surveys, however, showed that the Alaskan breeding population of Red-throated Loons declined by 53% from approximately 21,000 birds in 1977 to 10,000 in 1993 (Groves et al. 1996). Results of our satellite tracking study found that the wintering Red-throated Loons we tagged in the mid-Atlantic comprised a largely unstudied source breeding population encompassing a huge swath of the Canadian Arctic. Demographic information related to this population is lacking, which limits our ability to detect trends in their distribution and abundance, and highlights a need for coordinated monitoring efforts. The high degree of uncertainty linked to seabird mortality estimates associated with turbine collisions and the population consequences of displacement further necessitates the need for information that can be used to improve the reliability of collision risk and population model predictions (Bailey et al. 2014). Therefore, it is essential that plans to acquire empirical data on seabird responses during the construction and post-construction phases of new wind energy areas are incorporated into development proposals. Prior to construction, strategic planning can help mitigate the potential effects of offshore wind energy development by making informed siting decisions based on the results of this and other baseline studies of animal populations in the mid-Atlantic. Integrating such information on the distribution and abundance of animals in the region will help to identify priority sites for development where adverse effects are expected to be minimized. Drewitt and Langston (2006) noted that, whenever possible, developers should avoid areas where high densities of wintering and migratory seabirds occur, particularly for species of conservation concern. In order to better understand the potential effects of offshore wind energy development on birds, baseline information provided by our study could be utilized to distinguish the results of offshore energy development from natural variation in bird abundance during future post-construction monitoring efforts (Fox et al. 2006).

Table 3-1. Argos locations classes and their assigned errors in meters used in the dynamic Brownian bridge movement models.

Argos location class	Mean error (m)
3	1,500
2	3,300
1	7,600
0	17,200
A	15,000
B	20,900
Z	18,600

Table 3-2. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 95% “home range” utilization distribution (UD) of adult Red-throated Loons on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (UD area in sq. km)	Fall migration (62,2438.9)		Winter (31,421.3)		Spring migration (68,3716.8)	
WEA/Lease Area names (area in sq. km)	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**
MA OCS-A 0478 (119.1)	100	0.02	0	0	100	0.02
RI / MA OCS-A 0486 (394.6)	0.77	0	0	0	100	0.06
MA OCS-A 0501 (675.6)	38.96	0.04	0	0	100	0.1
MA OCS-A 0500 (759.0)	42.72	0.05	0	0	100	0.11
RI / MA OCS-A 0487 (272.2)	1.26	0	0	0	100	0.04
MA OCS-A 0502 (1004.1)	27.83	0.04	0	0	100	0.15
MA OCS-A 0503 (569.1)	62.86	0.06	0	0	100	0.08
NY Proposed Commercial Lease Unsolicited (165.6)	0	0	0	0	100	0.02
NY OCS-A 0512 (321.2)	2.28	0	0	0	100	0.05
NJ OCS-A 0499 (742.1)	0	0	2.73	0.06	100	0.11
NJ OCS-A 0498 (649.9)	0	0	0	0	100	0.1
DE OCS-A 0482 (390.5)	29.21	0.02	2.94	0.04	100	0.06
MD OCS-A 0489 (132.6)	3.08	0	0	0	100	0.02
MD OCS-A 0490 (190.2)	0	0	0	0	100	0.03
VA OCS-A 0483 (456.8)	0	0	0	0	31.93	0.02
VA OCS-A 0497 (8.6)	0	0	0	0	0	0
NC OCS-A 0508 (495.8)	0	0	0	0	8.17	0.01
SC Call Area - Grand Strand (2673.1)	0	0	0	0	0	0
NC WEA - Wilmington West (208.6)	0	0	0	0	0	0
NC WEA - Wilmington East (540.1)	0	0	0	0	0	0
SC Call Area - Cape Romain (652.4)	0	0	0	0	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	12.78	0.24	0.27	0.1	56.9	0.96

Table 3-3. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 50% “core use” utilization distribution (UD) of adult Red-throated Loons on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (Core area in sq. km)	**Fall migration (59,497.9)**		**Winter (5,500.7)**		**Spring migration (25,261.4)**	
WEA/Lease Area names (area in sq. km)	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**	**% of WEA/Lease Area within UD**	**% of total UD area overlapped**
MA OCS-A 0478 (119.1)	0	0	0	0	53.91	0.25
RI / MA OCS-A 0486 (394.6)	0	0	0	0	0	0
MA OCS-A 0501 (675.6)	0	0	0	0	0	0
MA OCS-A 0500 (759.0)	0	0	0	0	0	0
RI / MA OCS-A 0487 (272.2)	0	0	0	0	0	0
MA OCS-A 0502 (1004.1)	0	0	0	0	0.68	0.03
MA OCS-A 0503 (569.1)	0	0	0	0	0	0
NY Proposed Commercial Lease Unsolicited (165.6)	0	0	0	0	0	0
NY OCS-A 0512 (321.2)	0	0	0	0	0	0
NJ OCS-A 0499 (742.1)	0	0	0	0	0.01	0
NJ OCS-A 0498 (649.9)	0	0	0	0	0	0
DE OCS-A 0482 (390.5)	0	0	0	0	0	0
MD OCS-A 0489 (132.6)	0	0	0	0	0	0
MD OCS-A 0490 (190.2)	0	0	0	0	0	0
VA OCS-A 0483 (456.8)	0	0	0	0	0	0
VA OCS-A 0497 (8.6)	0	0	0	0	0	0
NC OCS-A 0508 (495.8)	0	0	0	0	0	0
SC Call Area - Grand Strand (2673.1)	0	0	0	0	0	0
NC WEA - Wilmington West (208.6)	0	0	0	0	0	0
NC WEA - Wilmington East (540.1)	0	0	0	0	0	0
SC Call Area - Cape Romain (652.4)	0	0	0	0	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	0	0	0	0	0.62	0.28

Table 3-4. Comparison of generalized linear models examining second order resource selection effects of habitat characteristics on the probability of adult Red-throated Loon (*n* = 39) winter home range use in the Middle Atlantic Bight (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll a, dist = distance to shore, SED = sediment type, depth = water depth, SSS6 = 6-yr mean winter sea surface salinity). Models are ranked according to Akaike Information Criterion (AIC). The table shows the variables included in the model, number of estimated parameters (*K*), differences between model Akaike Information Criterion (ΔAIC), and AIC weights (w_i).

Model	***K***	**AICc**	**ΔAICc**	**w_i**
dist+CHLOR10+SST10+SSS6+SED	6	16068.7	0.00	1.00
dist+CHLOR10+SST10+SSS6	5	16262.8	194.06	0.00
dist+CHLOR10+SST10	4	16610.1	541.36	0.00
dist+CHLOR10	3	18736.9	2668.16	0.00
Dist	2	18998.6	2929.87	0.00
null model	1	41049.8	24981.08	0.00

Table 3-5. Scaled estimated coefficients (β) and standard errors (SE), odds ratios (OR) and confidence intervals (CI), and P-values for the variables in the top AIC-ranked generalized linear model predicting second order resource selection of adult Red-throated Loon (*n* = 39) winter home range selection in the Mid-Atlantic Bight, 2012-2016 (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll a, SSS6 = 6-yr mean winter sea surface salinity).

Fixed Effects	**Scaled β**	**SE**	**OR**	**CI**	**P**
(Intercept)	-5.40	0.06	0.00	0.00 – 0.01	<0.001
Distance from shore (km)	-6.48	0.03	0.00	0.00 – 0.00	<0.001
SST10 (°C)	1.18	0.04	3.25	3.08 – 3.43	<0.001
CHLOR10 (mg/m3)	0.74	0.07	2.09	1.97 – 2.22	<0.001
SSS6 (PSU)	-0.51	0.05	0.60	0.55 – 0.65	<0.001
Sediment grain size					
0.03 – 0.17 (mm) sand	1.09	0.05	2.97	2.34 – 3.78	<0.001
0.17 – 0.35 (mm) sand	1.02	0.06	2.78	2.20 – 3.53	<0.001
0.35 – 0.36 (mm) sand	0.26	0.06	1.30	0.99 – 1.69	0.057
0.36 – 0.48 (mm) sand	1.01	0.07	2.74	2.12 – 3.55	<0.001
0.48+ (mm) gravel	0.88	0.06	2.41	1.88 – 3.09	<0.001

Table 3-6. Comparison of estimated means (SD) of habitat characteristics measured at used locations in the winter home range of adult Red-throated Loons (*n* = 39) versus randomly generated available locations within the Mid-Atlantic Bight.

	Utilization Distribution Isopleth			
	Used		Available	
Habitat Variable	Mean (SD)	Range	Mean (SD)	Range
10-yr mean winter chlorophyll *a* (mg/m^3)	6.58 (4.54)	0.43 - 26.07	1.93 (2.24)	0.29 - 26.07
10-yr mean winter sea surface temperature (°C)	8.26 (3.81)	4.09 - 19.83	9.42 (3.16)	4.10 - 20.93
6-yr mean winter sea surface salinity (PSU)	31.80 (2.93)	16.84 - 36.02	33.43 (1.12)	16.84 - 36.32
Water depth (m)	15.26 (8.58)	0.10 - 282.80	419.25 (736.39)	0.10 - 80.80
Distance from shore (km) (all years)	8.96 (5.81)	0.10 - 46.95	76.88 (52.45)	0.10 - 228.49

Table 3-7. Frequency of sediment grain sizes (mm) at *used* locations included in the generalized linear model predicting second order resource selection of the winter home range of adult Red-throated Loons (n = 39) versus randomly generated *available* locations across the Middle Atlantic Bight.

	Frequency of Use		**Probability of Use**	
Sediment Type	***Available***	***Used***	***Available***	***Used***
0.00 - 0.03 mm Silt/Mud	3317	390	0.16	0.04
0.03 – 0.17 mm Sand	4148	2219	0.19	0.21
0.17 – 0.35 mm Sand	5005	4310	0.24	0.40
0.35 – 0.36 mm Sand	2849	1016	0.13	0.09
0.36 – 0.48 mm Sand	2191	1189	0.10	0.11
0.48+ mm Gravel	3767	1657	0.18	0.15
Total	21,277	10,781	1.00	1.00

Table 3-8. Comparison of generalized linear mixed models examining the effect of habitat characteristics on the probability of third order resource selection of core use areas by adult Red-throated Loons (*n* = 41) within the mid-Atlantic winter home range (SST10 = 10-yr mean winter sea surface temperature, CHLOR10 = 10-yr mean winter chlorophyll a, dist = distance to shore, SED = sediment grain size, depth = water depth, SSS6 = 6-yr sea surface salinity). Models are ranked according to Akaike Information Criterion (AIC). The table shows the variables included in the model, number of estimated parameters (*K*), differences between model Akaike Information Criterion (ΔAIC), and AIC weights (w_i).

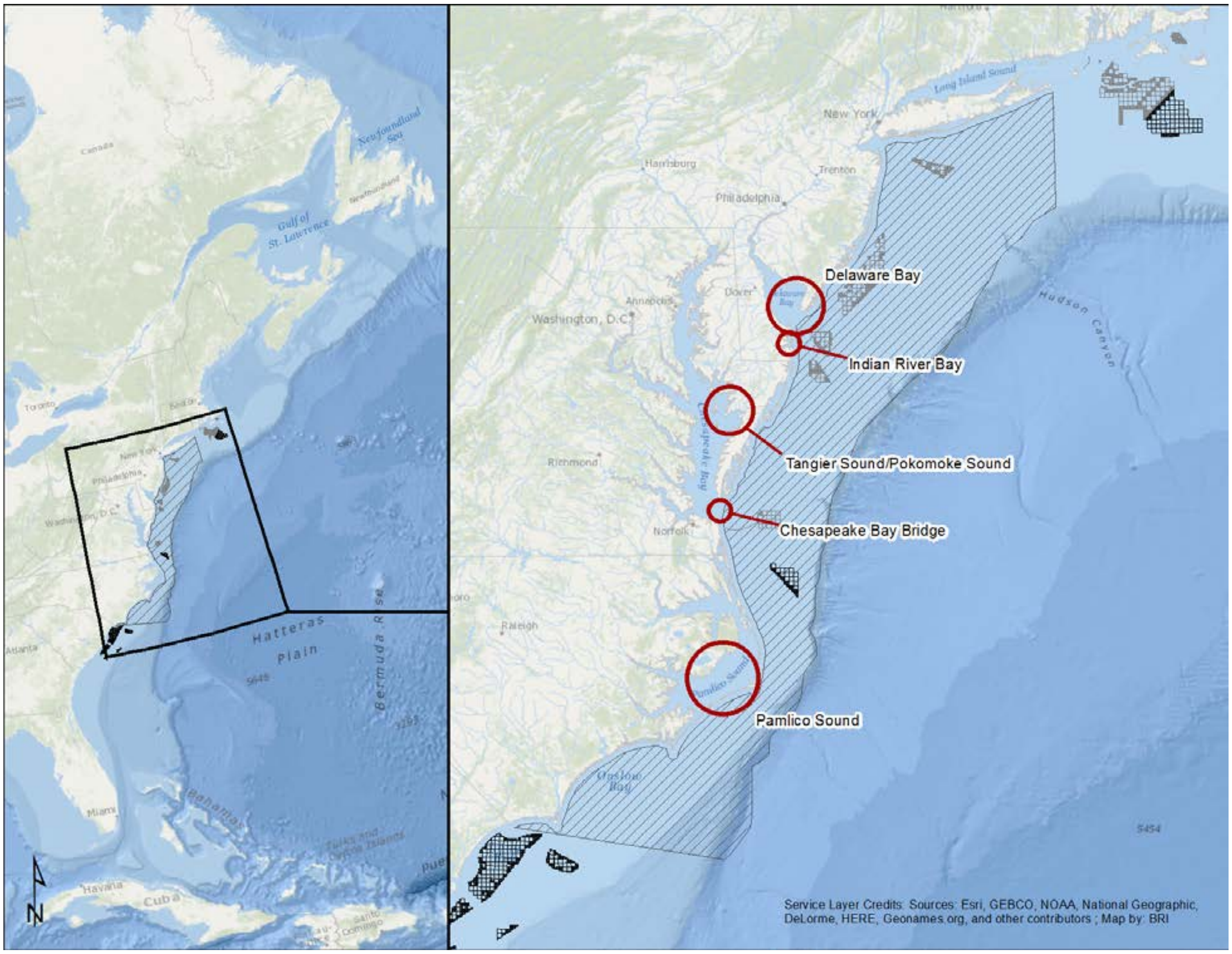
Model	***K***	**AICc**	**ΔAICc**	**w_i**
(1|animal)+depth+CHLOR10+SSS+dist	6	9771.8	0.00	0.67
(1|animal)+depth+SST10+CHLOR10+SSS+dist	7	9773.2	1.39	0.33
(1|animal)+depth+SST10+CHLOR10+SSS	6	10264.9	493.10	0.00
(1|animal)+depth+SST10+CHLOR10	5	10287.2	515.38	0.00
(1|animal)+depth	3	10390.6	618.87	0.00
(1|animal)+depth+SST10	4	10390.8	619.00	0.00
(1|animal)	2	11050.5	1278.75	0.00
Null model	1	12015.4	2243.64	0.00

Table 3-9. Scaled estimated coefficients (β), odds ratios (OR), confidence intervals (CI), standard errors (SE), and P-values of the fixed effects in the top AIC-ranked generalized linear mixed model predicting third order resource selection of core winter habitat use areas by adult Red-throated Loons (*n* = 41) within the Mid-Atlantic winter home range (CHLOR10 = 10-yr mean winter chlorophyll a, SSS= mean monthly sea suface salinity). Animal ID was included as a random effect to allow the intercept to vary among individuals and results shown include: between-animal-variance (τ_{00}); the number of individuals included in the model (N_{animal}); and the intraclass correlation among habitat measurements at locations of the same animal (ICC_{animal}).

	scaled β	**OR**	**CI**	**SE**	**P**
Fixed Effects					
(Intercept)	-1.99	0.14	0.08 – 0.24	0.29	< 0.001
water depth (m)	-0.30	0.74	0.68 – 0.80	0.04	< 0.001
CHLOR10 (mg/m^3)	0.23	1.25	1.16 – 1.35	0.04	< 0.001
SSS (PSU)	-0.22	0.80	0.75 – 0.87	0.04	< 0.001
distance from shore (km)	-0.86	0.42	0.39 – 0.46	0.04	< 0.001
Random Effect					
$\tau_{00, animal}$			2.991		
N_{animal}			41		
ICC_{animal}			0.476		

Table 3-10. Estimated means (SD) of habitat characteristics measured at adult Red-throated Loon (*n* = 41) locations in winter core use (0.50 utilization distribution; UD) and home range (0.95 UD) areas.

	0.50 UD		**0.95 UD**	
Habitat Variable	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
water depth (m)	12.09 (5.92)	1.00 – 42.20	16.11 (153.42)	0.10 – 282.80
distance from shore (km)	6.72 (3.57)	0.22 – 22.80	10.01 (6.10)	0.14– 46.95
SST (°C)	8.58 (3.01)	1.13 – 20.99	9.22 (3.86)	0.98 – 23.70
SST10 (°C)	7.59 (3.40)	4.27 – 17.88	8.17 (3.60)	4.10 – 19.83
CHLOR_*a* (mg/m^3)	6.26 (3.40)	1.56 – 28.55	5.90 (5.86)	0.28 – 65.89
CHLOR10 (mg/m^3)	7.89 (4.13)	1.34 – 20.19	6.31 (4.45)	0.43 – 26.07
SSS6 (PSU)	31.76 (2.59)	16.84 – 34.21	32.00 (2.50)	16.84 – 36.03
SSS (PSU)	30.76 (4.54)	15.58 – 35.99	31.94 (3.60)	11.44 – 36.38



Service Layer Credits: Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors ; Map by: BRI

Figure 3-1. The Mid-Atlantic study area (hatched area, right map) and the locations of Red-throated Loon captures (red circles) in this study. Capture efforts were concentrated in Delaware Bay (DE and NJ), Chesapeake Bay (MD and VA), and Pamlico Sound, NC. The federally designated Wind Energy Areas (WEAs) within and surrounding the study area are also included – light gray blocks = BOEM Lease Areas, dark gray blocks = BOEM Wind Planning Areas.

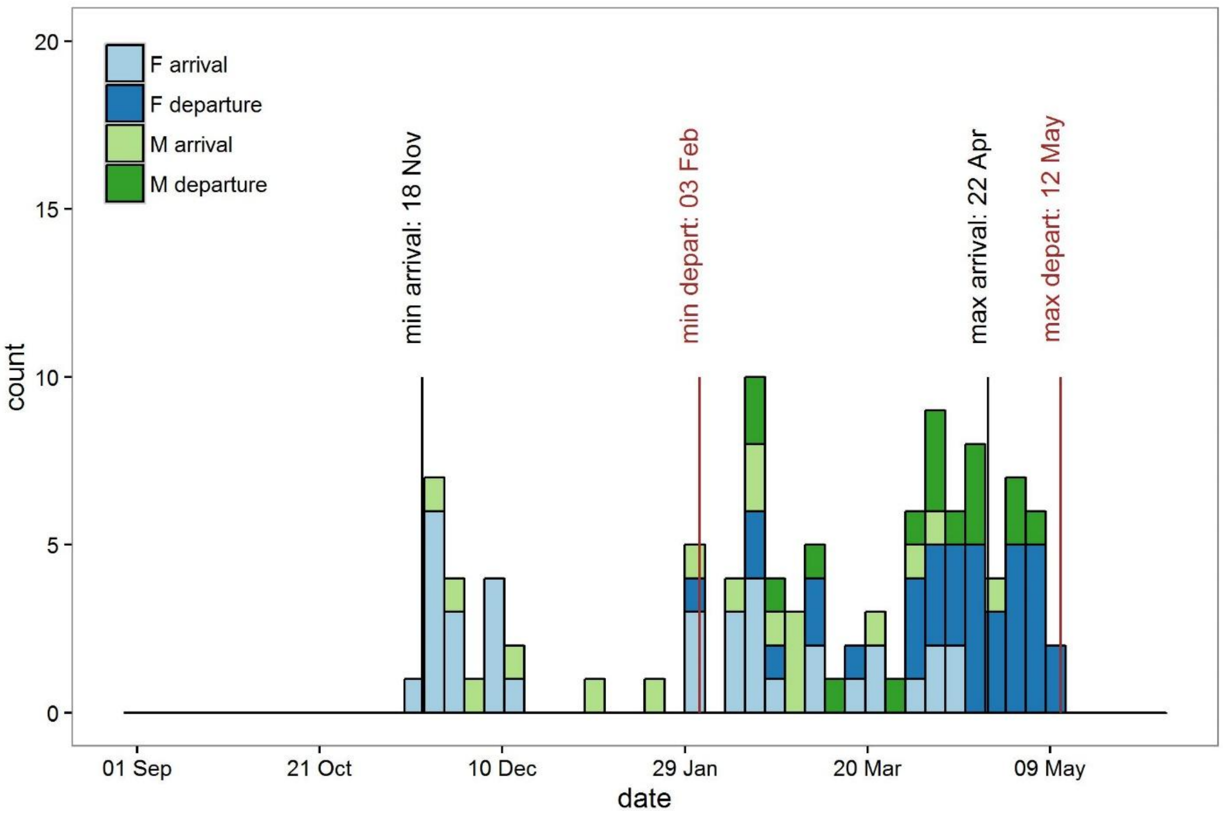


Figure 3-2. Distribution of mid-Atlantic study area arrival and departure dates by wintering adult male and female satellite-tagged Red-throated Loons, 2012 - 2015.

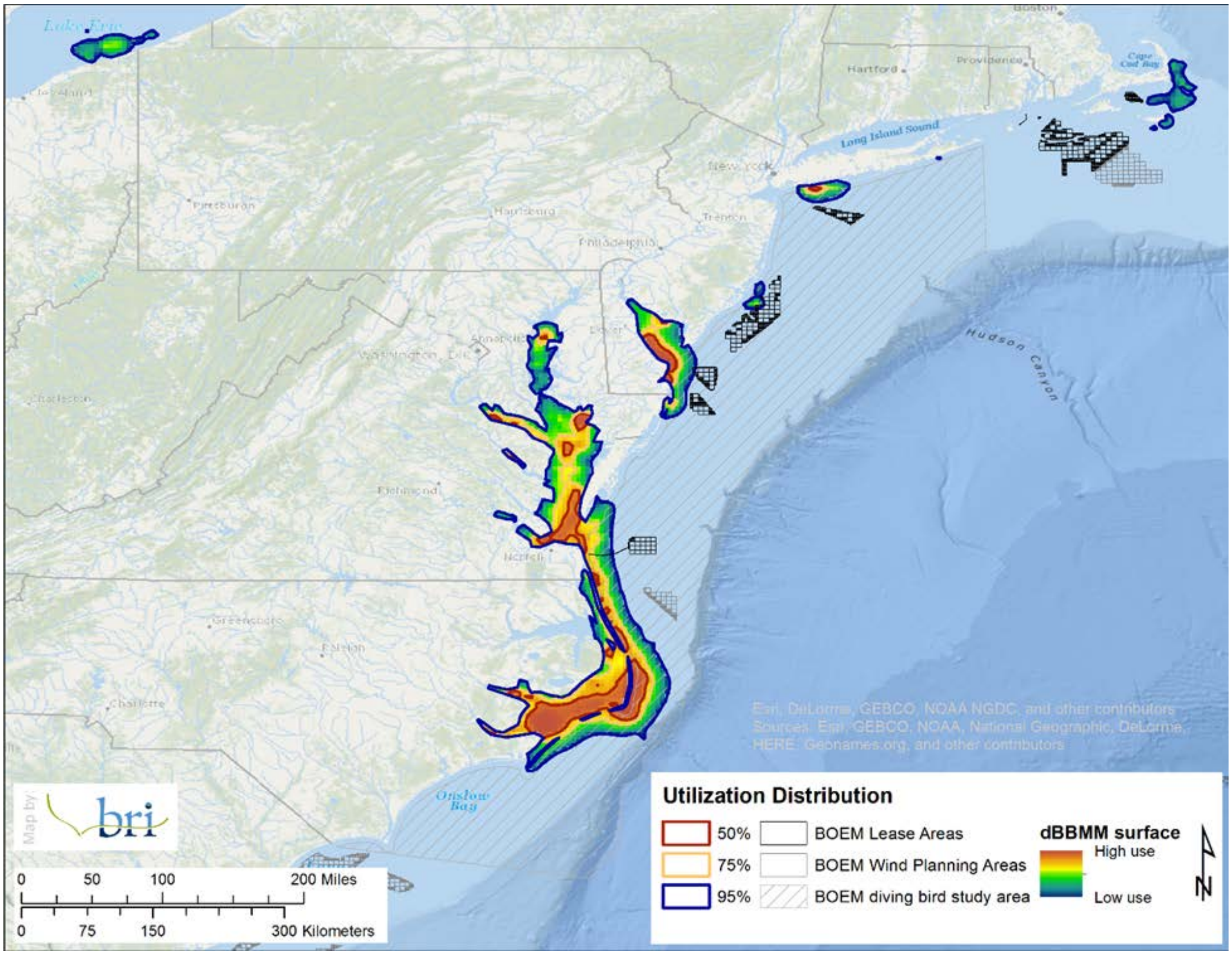


Figure 3-3. Winter use of areas within the mid-Atlantic study area by adult Red-throated Loons (*n* = 46) in relation to proposed offshore wind energy areas. Intensity of use ranges from lowest areas of use (blue) to greatest areas of use (red).

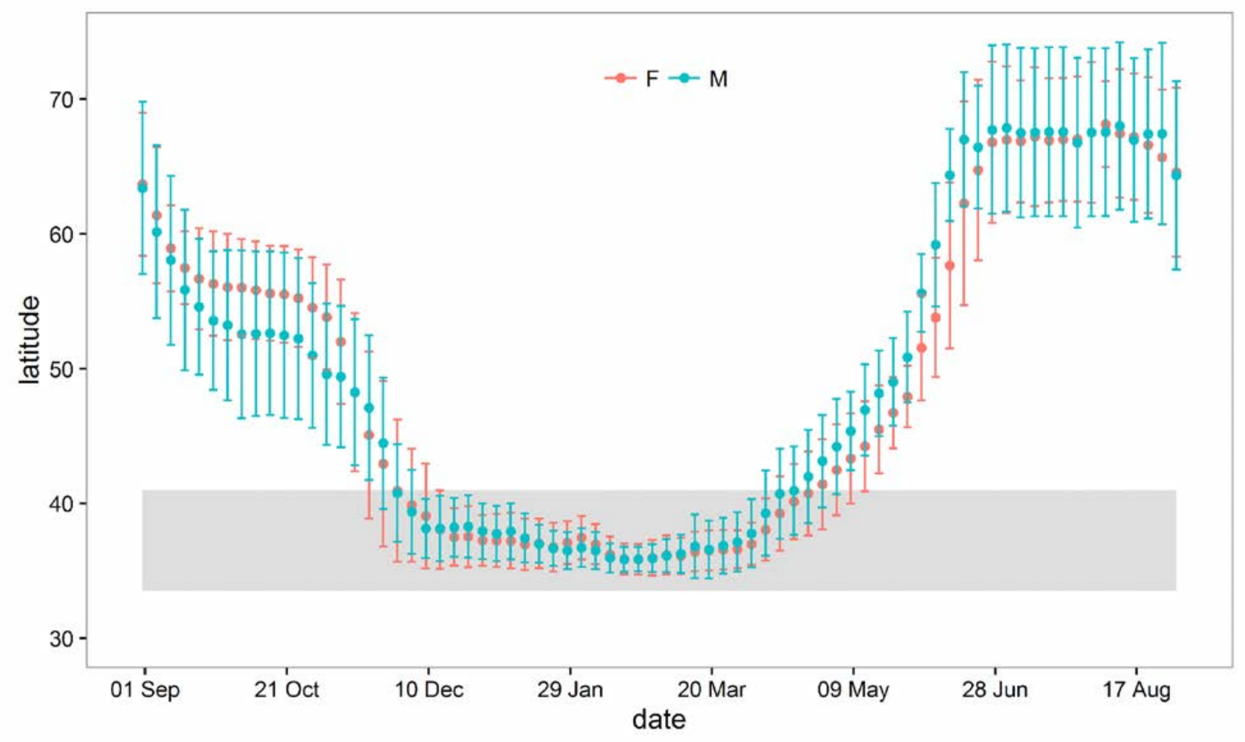


Figure 3-4. Mean ± SD latitude of satellite-tagged adult Red-throated Loons throughout their annual cycle. The gray box represents the latitude range of the mid-Atlantic winter study area.

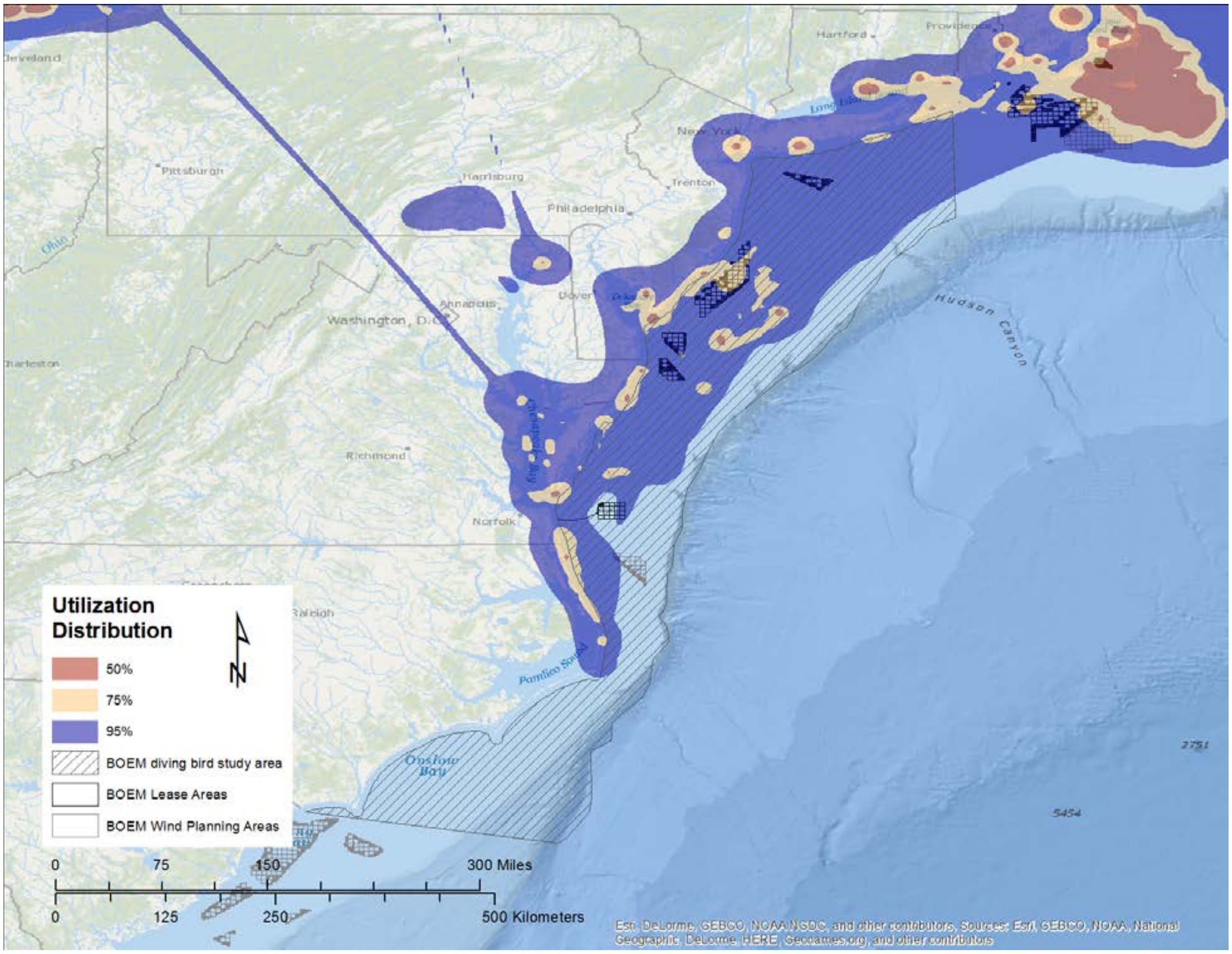
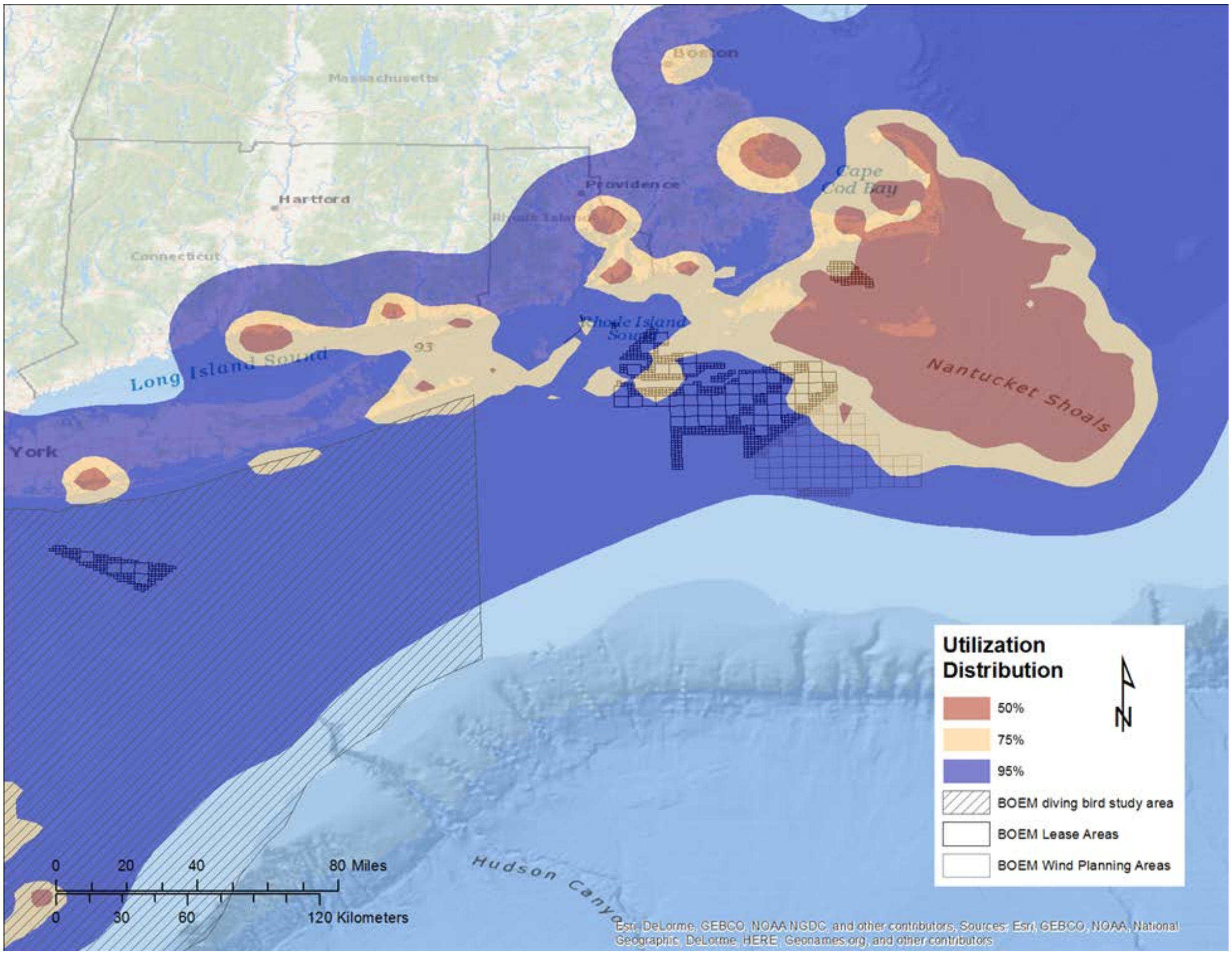


Figure 3-5. Utilization distribution of adult Red-throated Loons (*n* = 46) during the spring migration period, when birds were departing the mid-Atlantic study area (late March to early May, 2012 - 2015). Intensity of use ranges from lowest areas of use (blue) to greatest areas of use (red).



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 3-6. Utilization distributions of adult Red-throated Loons (*n* = 46) in southern New England in early spring migration during mid to late May, 2012 - 2015. Intensity of use ranges from lowest areas of use (blue) to greatest areas of use (red).

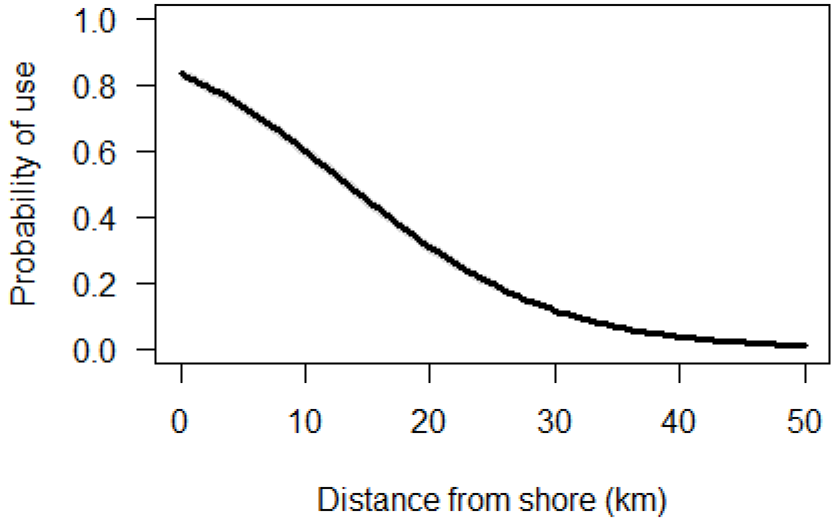


Figure 3-7. Generalized linear model results of the effect of distance from shore (km) on the probability of second order resource selection of winter home range areas by adult Red-throated Loons (*n* = 39; 24 females, 13 males, 2 unknown) within the Mid-Atlantic Bight.

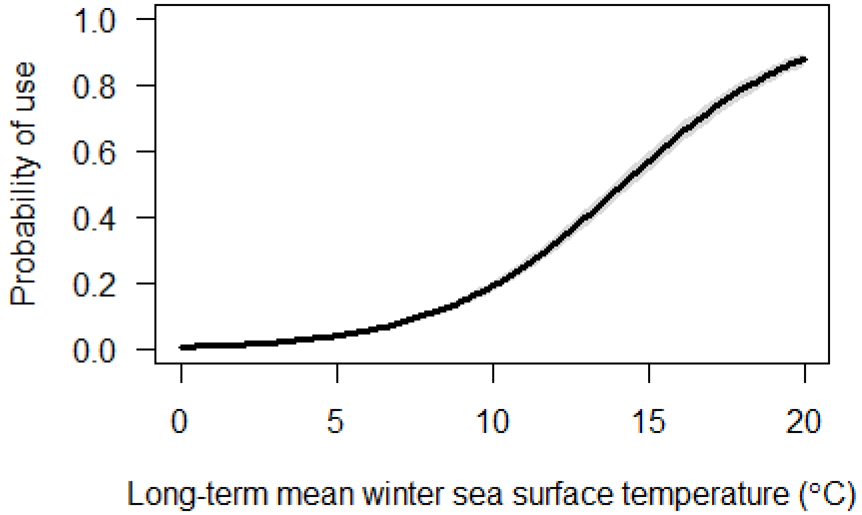


Figure 3-8. Generalized linear model results of the effect of long-term mean winter sea surface temperature (°C) on the probability of second order resource selection of winter home range areas by adult Red-throated Loons (*n* = 39; 24 females, 13 males, 2 unknown) within the Mid-Atlantic Bight.

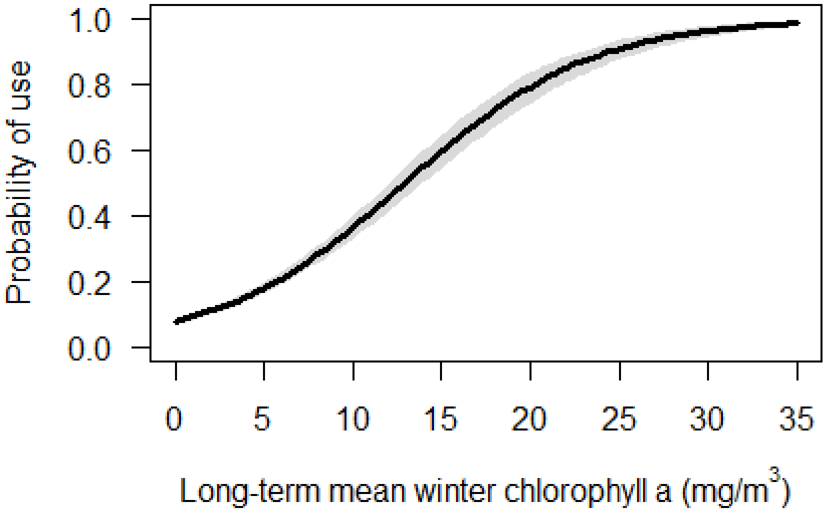


Figure 3-9. Generalized linear model results of the effect of long-term mean chlorophyll *a* (mg/m^3) concentrations on the probability of second order resource selection of winter home range areas by adult Red-throated Loons (*n* = 39; 24 females, 13 males, 2 unknown) within the Mid-Atlantic Bight.

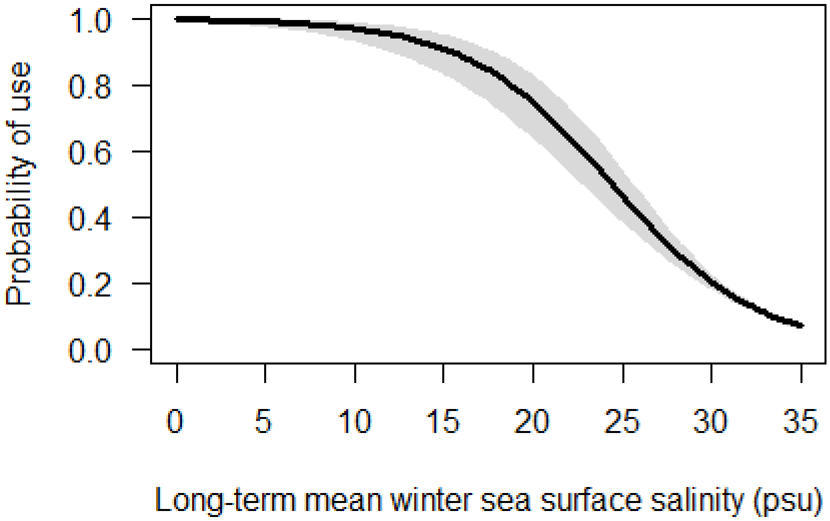


Figure 3-10. Generalized linear model results of the effect of long-term sea surface salinity (PSU; SSS6) on probability of second order resource selection of winter home range areas by adult Red-throated Loons (*n* = 39; 24 females, 13 males, 2 unknown) within the Mid-Atlantic Bight.

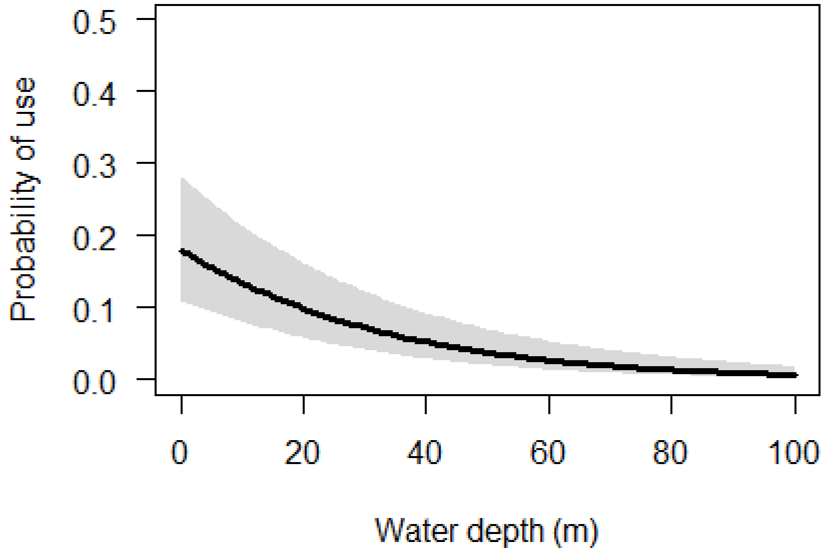


Figure 3-11. Generalized linear mixed model results of the effect of water depth (m) on probability of third order resource selection by adult Red-throated Loons (*n* = 41; 26 females, 13 males, 2 unknown) of winter core use areas within the Mid-Atlantic winter home range.

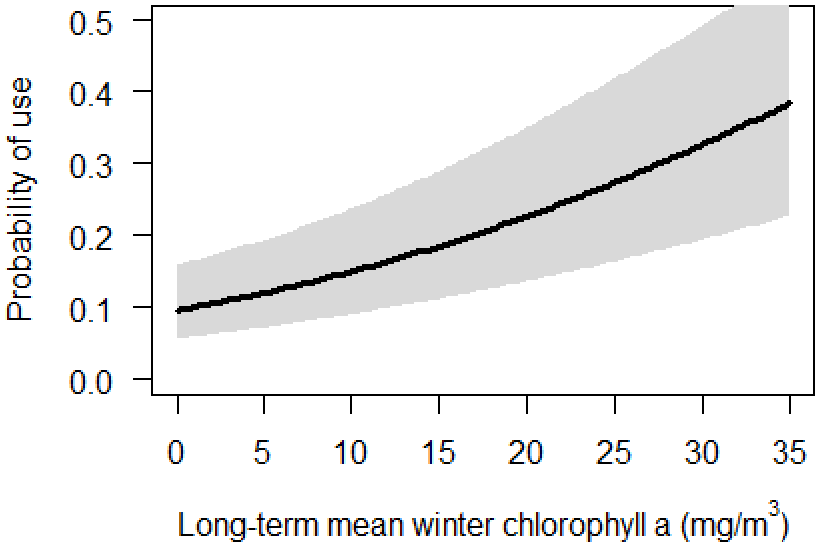


Figure 3-12. Generalized linear mixed model results of the effect of long-term mean winter chlorophyll *a* concentrations (mg/m^3) on probability of third order resource selection by adult Red-throated Loons (*n* = 41; 26 females, 13 males, 2 unknown) of winter core use areas within the Mid-Atlantic winter home range.

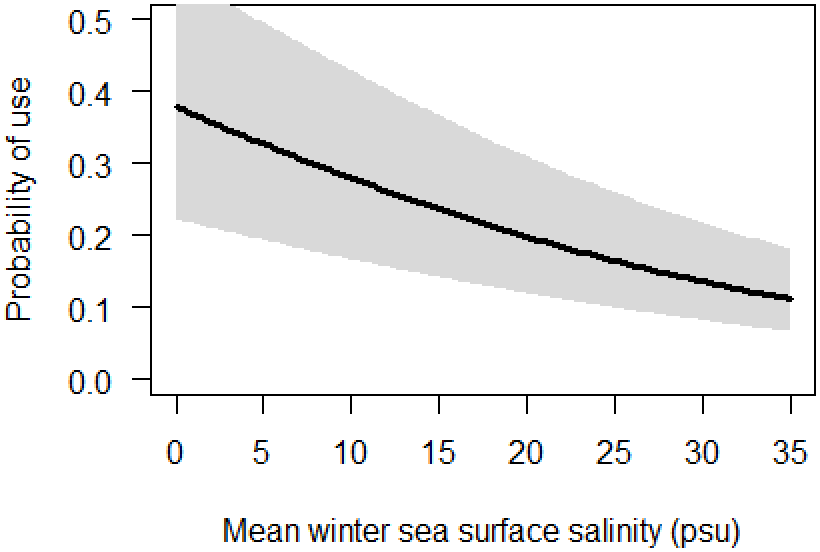


Figure 3-13. Generalized linear mixed model results of the effect of seasonal sea surface salinity (PSU) on probability of third order resource selection by adult Red-throated Loons (*n* = 41; 26 females, 13 males, 2 unknown) of winter core use areas within the Mid-Atlantic winter home range.

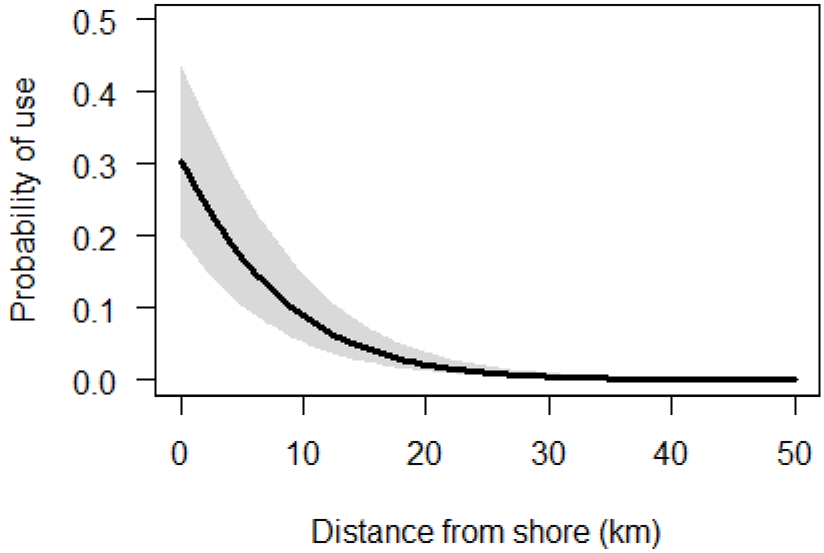
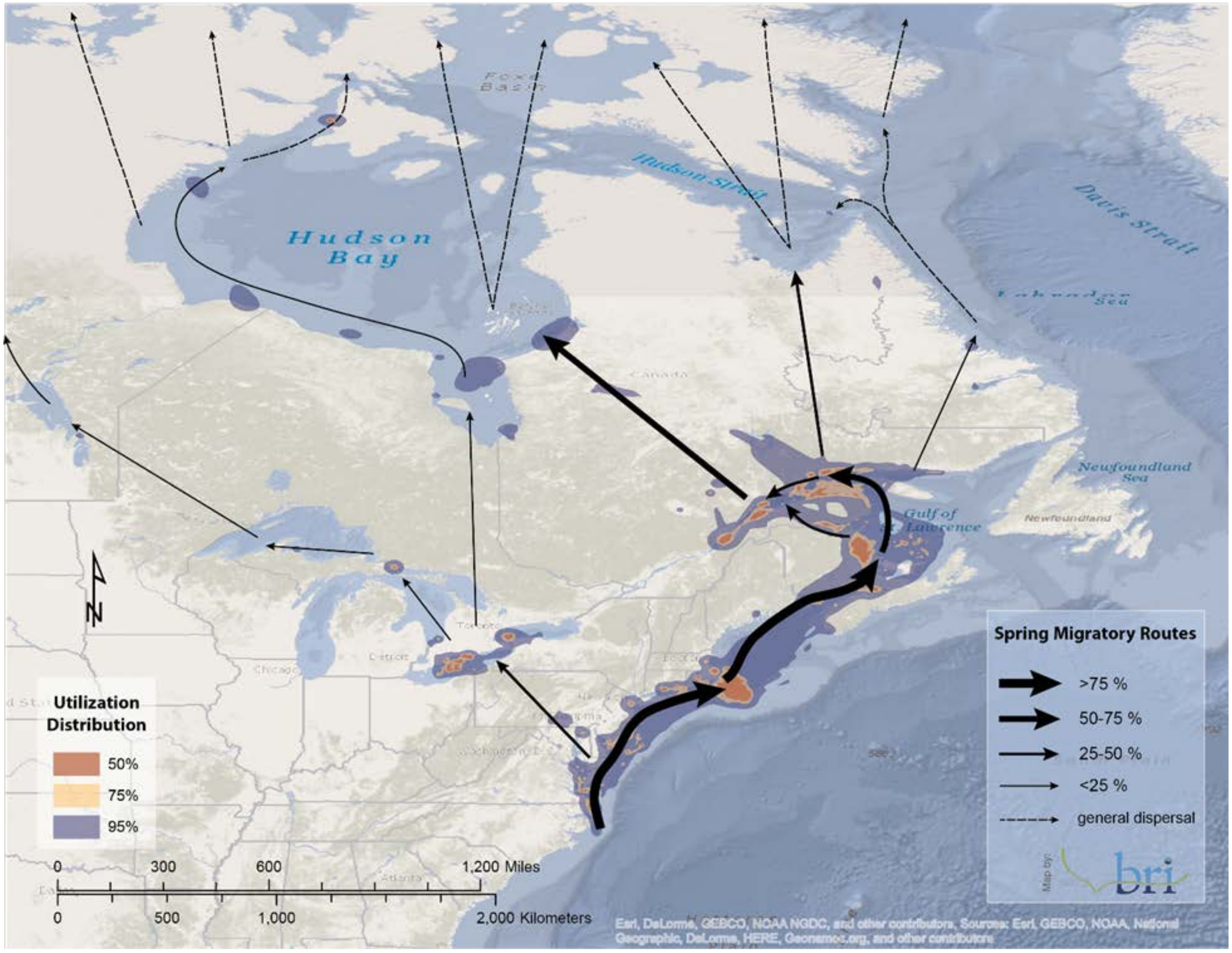
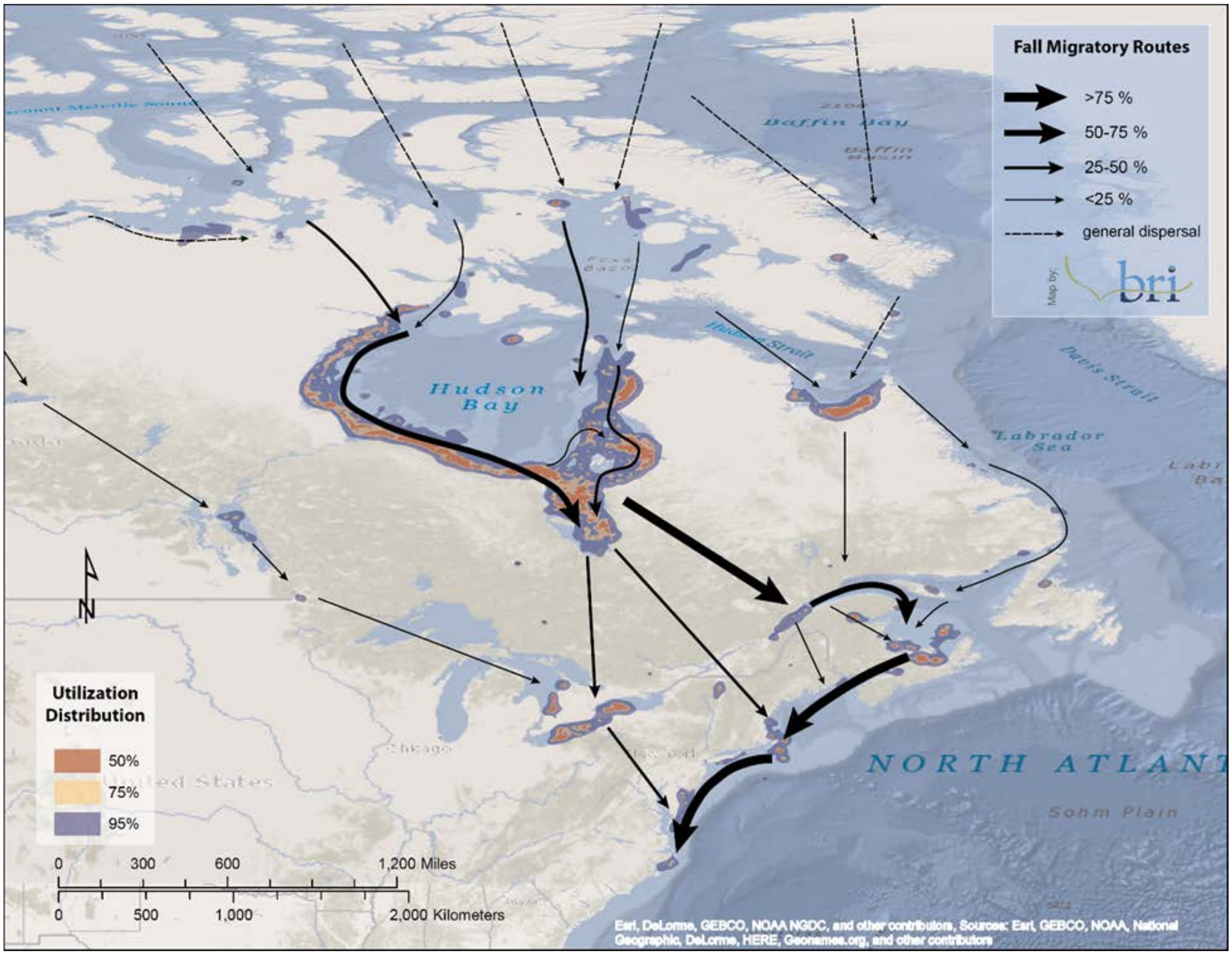


Figure 3-14. Generalized linear mixed model results of the effect of distance from shore (km) on probability of third order resource selection by adult Red-throated Loons (*n* = 41; 26 females, 13 males, 2 unknown) of winter core use areas within the Mid-Atlantic winter home range.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 3-15. Spring migration routes of adult Red-throated Loons (*n* = 46) tagged with satellite transmitters while on their mid-Atlantic wintering grounds, 2012 - 2015.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 3-16. Fall migration routes of adult Red-throated Loons (*n* = 31) tagged with satellite transmitters while on their mid-Atlantic wintering grounds, 2012 - 2015.

4. Occurrence and Migration of Surf Scoters Wintering in Offshore Waters of the Mid-Atlantic United States

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4.1 Summary

Offshore wind energy facilities are currently being planned and implemented for development in U.S. Atlantic waters. Offshore wind facilities may however impact many bird species, exposing them to potential mortality through turbine collisions, and by altering forage habitat, behavior and flight pathways. To evaluate the potential impact on marine birds by wind turbines in Federal waters (>5.6 km from shore), there is a need to collect information on the distribution, seasonal occupancy and behavior (e.g., flight pathways timing, etc.) of a broad suite of bird species utilizing these areas. Our project evaluated the fine-scale occurrence and movement patterns of Surf Scoters (*Melanitta perspicillata*) in the near-coastal federal waters of the U.S. mid-Atlantic area (North Carolina to Long Island, New York) from 2011 to 2016. Dynamic Brownian bridge movement modeling for both sexes of scoters showed that core-use areas during the wintering period encompassed the majority of both Chesapeake Bay and Delaware Bay, with additional smaller core-use areas occurring south of Cape Cod near Nantucket Shoals, in Long Island Sound, and in Pamlico Sound, NC. During spring migration, scoters followed a route within 18.5 km of the Atlantic coastline to staging areas near the Gulf of St. Lawrence. Surf Scoters were exposed to potential offshore wind energy areas from coastal New Jersey to coastal Massachusetts during migration, but very little potential exposure was found further south and during winter where scoters utilized near shore and bay habitats. Although Surf Scoters are not as likely to face exposure to wind facilities in federal waters as some other marine bird species, they could be more exposed to wind facilities operating concurrently in state-managed waters (<5.6 km offshore), and associated risks including mortality, alteration of available foraging habitat and/or altering bird movements further offshore or in-land.

4.2 Introduction

Summary reports of the status of sea ducks reveal population declines for some species with increased concern for the status of sea ducks in general (Elliot 1997; Kehoe 1994; Petersen and Hogan 1996). Surveys of sea ducks wintering on the Atlantic coast (1991-1999) showed major declines for the Surf Scoter (Caithamer et al. 2000) necessitating further research on this species. Surf scoters are indigenous to North America where they breed across northern Quebec and Alaska and their primary Atlantic coast wintering area is the Chesapeake Bay (Savard et al. 1998). More recent sea duck surveys conducted along the Atlantic coast (2009-2011) have shown a 40% decline in sea duck counts and abundance estimates, with Surf Scoters and Long-tailed Ducks (*Clangula hyemalis*) exhibiting the largest declines (Silverman et al. 2013). These declines induced the continuation of sea duck surveys along the Atlantic and initiated satellite telemetry projects to delineate migration routes, wintering, molting, and breeding areas, for the purpose of informing and refining survey designs. These surveys also noted that 41% of the estimated sea ducks were around Cape Cod, Nantucket, and the Nantucket Shoals; 24% were found within the Chesapeake Bay and off the Maryland and Delaware coasts with the remaining 35% distributed throughout the remaining coastline areas (Silverman et al. 2013). With recent offshore wind farm development plans, the focus of telemetry studies has switched from long-range migration and general use areas to fine scale habitat utilization throughout their coastal range.

Multiple factors influence the distribution of a species during the non-breeding season, such as habitat quality, food supply, predation pressures, and behavioral characteristics (Newton 2008). Understanding the physical and biological habitat requirements of a species throughout their annual cycle is critical for effective wildlife management. Research suggests that the quality of habitat occupied on the wintering grounds can result in carryover effects in subsequent seasons, including the timing or capacity to migrate, breed, or survive (Marra et al. 1998, Studds and Marra 2005). Optimal quality habitat is often indicated by the persistent annual occupancy of an area by individuals of a given species (Faaborg et al. 2010). Spatially-explicit patterns of use can be related to the distribution of resources within the landscape in order to identify the characteristics of high-quality habitat, which are expected to be occupied for longer periods within a season and more consistently over time in comparison to low-quality habitats (Boyce and McDonald 1999, Manly et al. 2002, Johnson 2007). Further, observations of animal occupancy can be used to predict habitat use across landscapes or to understand the influence of certain habitat characteristics on a species distribution (Long et al. 2009).

Scoters commonly feed in shallow marine coastal waters <10 m deep, usually over substrates of pebbles and sand (Savard et al. 1998), and prey on stationary organisms (mussels, clams) in flocks ranging from a few to several thousand birds (Cottam 1939, Stott and Olson 1973, Vermeer 1981, Žydelis 2006). Stott and Olson (1973) found a preferential use of sandy substrates by Surf Scoters along the New Hampshire coastline, with decreasing abundance as the percentage of rocky habitat increased. Kidwell (2007) found that Surf Scoters wintering in the Chesapeake Bay select against mud/silt habitats and prefer to forage in hard bottom interspersed with sand or homogenous sandy habitats and occurred nearshore (depths of 10-25 m). Coastal surveys indicate that the vast majority of scoters (mainly Surf Scoter) wintering on the Canadian Pacific Coast occur within 1 km of land (Savard et al. 1998). Silverman et al. (2009) reported that 90% of all the scoter groups recorded were within 7 nautical miles (nm) of the shore, which includes the zone of > 3 nm from the coast, designated as federal waters where numerous offshore wind energy areas are proposed along the Atlantic coast.

Studies of offshore wind facilities in Europe suggest that wind energy development can impact seabirds through direct and indirect effects such as turbine mortality, displacement through disturbance, foraging habitat loss, and creation of artificial reef habitat providing additional food resources (Tulp et al. 1999, Petersen 2005, Petersen et al. 2006, Furness et al. 2013, Dierschke et al. 2016). Many offshore wind projects have been proposed along the Atlantic coast ranging from Maine to North Carolina, despite highly variable results on impacts of offshore wind farms on similar species found in Europe, one common key recommendation was the placement of the wind energy areas to minimize impact on seabirds. The parallel interests among the Sea Duck Joint Venture (SDJV; 2015) and this study provided a strong partnership to begin investigating the timing and fine-scale movements of Surf Scoters in the mid-Atlantic region with a goal of informing the siting of leases to minimize the impacts on migrating and wintering Surf Scoters. Beginning in the winter 2011-2012, we partnered with the SDJV to deploy satellite transmitters on Surf Scoters within areas of the mid-Atlantic region known to support high concentrations of wintering individuals, and offshore wind energy areas and Lease Areas.

4.3 Methods

4.3.1 Additional Data

Due to a lack of basic knowledge about sea duck biology, migration, and habitat use, the SDJV and project partners initiated the Atlantic and Great Lakes Sea Duck Migrations Study, a multi-year study to help identify near-shore and offshore areas of the Atlantic coast and Great Lakes where wind power facilities and other developments would have the least impact on sea ducks (Sea Duck Joint Venture 2015). The SDJV work is generating a wealth of detailed information on coastal and marine habitats used by sea ducks throughout the year, and complements the BOEM mid-Atlantic diving bird project.

4.3.2 Study Area

The priority study area included waters off the U.S. Atlantic coast from Long Island, NY to the southern border of North Carolina (Figure 4-1); however, results include all U.S. Atlantic Federal waters with potential offshore wind development. Three winter capture regions were selected: Delaware Bay, DE, Chesapeake Bay, MD and VA, and Pamlico Sound, NC. These sites were selected because they were adjacent to our study area, were known to host high numbers of wintering scoters, and permitted safe (for researchers and birds) and efficient at-sea capture. Capture efforts were focused as close to Federal waters as safely feasible, often at the mouths of the bays as much as weather allowed; however, Choptank River, Chesapeake Bay was also utilized for capture since it has high concentrations of wintering scoters.

4.3.3 Capture

Surf scoters were captured during winter and migration from 2011-2015 using a variety of techniques depending on local conditions. Capture techniques included night-lighting, over-water mist netting (Brodeur et al. 2008), and net-gunning from a boat (Sea Duck Joint Venture 2015). Capture areas for the BOEM study occurred during the winter period and included high density scoter areas of Delaware Bay, Chesapeake Bay, and Pamlico Sound. Project partners involved in the Sea Duck Joint Venture's Atlantic and Great Lakes Sea Duck Migration Study contributed complementary Surf Scoter telemetry data from the Gulf of St. Lawrence River. (For more information about trapping techniques, see http://seaduckjv.org/catch/to_catch_a_sea_duck .pdf.)

4.3.4 Surgery and Post-operative Care

The scoters were surgically implanted with Telonics IMPTAV-2640 (45 g) platform terminal transmitter satellite tracking tags (PTTs) in the abdominal cavity by a qualified veterinarian following the technique described by Korschgen et al. (1996). At the veterinarian's discretion, transmitters were wrapped in a sterile mesh to promote additional surface area for adhesion to the body wall, and created additional anchoring points to stabilize the PTT within the bird (Figure 4-2). PTTs were pressure-proofed to prevent crushing if ducks dived to great depth. The surgical team closely monitored the recovery of the birds and returned them as quickly as possible to the area of capture. Scoters were transported and recovered post-operative in specially designed pet carriers, which contained a raised mesh floor and covered with wood shavings to allow the birds to remain clean and dry. Although some ducks were held more than one day in earlier projects, the current protocol is to hold radio-tagged birds in captivity for up to 3 hours post-surgery then release them at or near the capture site (see Chapter 5 for details). All field procedures, including surgical implantation of tags, were reviewed and approved under Institutional Animal Care and Use Committee number 2010-10 (USGS-PWRC).

4.3.5 Transmitter Programming

All PTTs were programmed with duty cycles that represent a compromise between PTT longevity and frequency of location data, intended to meet multiple objectives. For example, more frequent location data would better characterize habitats used at relatively small geographic or temporal scales, whereas less frequent data but greater longevity provides better information on inter-annual site fidelity and variation in migration patterns. The duty cycle currently in use for SDJV is 2 hrs ON and 72 hrs OFF (i.e., one location every 3 days). This was selected to achieve two full years of data and, possibly up to three years for the larger units with more battery life. The BOEM PTTs were on more frequent cycles to determine daily movements during migration and winter periods, with a maximum reporting frequency of 4 hours ON and 13 hours OFF. During dates the birds were expected to be on the breeding grounds away from the BOEM study area, the reporting frequency of the transmitters was reduced (2 hours ON 120 hours OFF) to conserve battery life.

4.3.6 Telemetry Data Processing and Analysis

Telemetry data from PTTs are collected using the Argos system of satellites (http://www.argos-system.org/). A customized program written in the Python programming language (Python 2.7, http://www.python.org/) was created for downloading data at five-day intervals. Data for all active tags were retrieved by the program. Argos data from this study were stored or archived at several locations including MoveBank (www.movebank.org) and servers at the USGS Patuxent Wildlife Research Center and Biodiversity Research Institute.

We compiled and analyzed archived data to remove redundant data and flag errant points using the Douglas Argos Filter (DAF, http://alaska.usgs.gov/science/biology/spatial/douglas.html). The DAF is a threshold filter that has several user-defined parameters to flag improbable locations in satellite tracking data (Douglas et al. 2012). The parameters are adjustable based on species' movement behaviors and the geographic scale of the area under observation. With the DAF, data are retained if they pass: 1) a spatial redundancy test and/or 2) a movement rate and turning angle test. As bird data contain both short-distance, local movements and long-distance migratory events, we employed the hybrid filter of both the distance, angle and rate (DAR) and minimum redundant distance (MRD) filters. This achieved the best of both filters and in practice has produced very clean data with few erroneous points.

We compiled a database of deployment and life-history data for every PTT that was deployed or archived by the BOEM (2012-2014) and SDJV (2011-2014) projects. The database was made available to partners for editing and contained information about the PTT tags themselves, data on the capture and deployment history of all birds. “Life-history period” start and end dates were noted for every animal, following species-specific life-stage criteria defined by the SDJV (Sea Duck Joint Venture 2015). We identified the following life-history periods: breeding, molting, fall-staging, wintering, and spring-staging, for every year that the animal was alive and transmitted locations. We assigned final dispositions (alive, dead, tag failure, or unknown) and the date of disposition for all non-active tags. We assessed sensor data for every tag to identify bird mortality (by internal body temperature sensor or mortality sensor) or battery/tag failure due to low transmitter voltage. We listed the day after last transmission as the last date of disposition for all birds with tags that stopped transmitting for either low voltage or unknown reasons. We calculated tag duration dates from the deployment start date and the final disposition date. Maps presented in this report include DAF-filtered data through June 2016.

4.3.7 Data Preparation for Geospatial Analysis and Mapping

We wrote a custom script in R 3.3 (R Core Team 2016) to automate preparation of data for geospatial analysis and mapping. This script used the DAF-filtered data and the corresponding life-history period data from the deployment database to assign points to seasonal period for each individual. We included in analyses no more than a single representative year of data over no more than two years per animal per season (e.g., winter, fall migration) to avoid biasing the analyses towards individuals with more years of data. Prior studies on ducks (Mulcahy and Esler 1999, Sexson et al. 2014) indicated that behavior might be most affected by tag implant surgery during the first 14 days after the procedure, resulting in movement patterns not representative of the normal behavior of that animal during this time. In our study, most mortalities likely resulting from implantation occurred within 30 days of surgery. In almost every case, these birds displayed movement behaviors that deviated from that of birds that did not die within 30 days, such as travel far up rivers or onto land. Therefore, we omitted birds that transmitted < 30 days after release from analyses to reduce bias from birds that could have been negatively affected by transmitter implantation and handling. Overall this made up a very small fraction of our sample. We filtered the remaining data using the DAF assigned hybrid filter to remove redundant points and those determined to have incorrect locations based on the turning angle and movement rate tests, keeping the remaining locations for analyses. We assigned mean errors (Douglas et al. 2012) to location classes (Table 4-1) for use in dynamic Brownian-bridge movement analyses which includes location errors in analyses (Kranstauber et al. 2012). We used the 95th error percentiles for data using the parameter MAXREDUN = 15 km in the DAF filter. While this is a liberal error assignment for locations, in practice the models are robust to changes in such values.

4.3.8 Brownian-bridge Movement Analysis of Winter and Migration Periods

We determined sample population level utilization distributions for each species by calculating individual level dynamic Brownian-bridge movement model (dbbmm) surfaces (Kranstauber et al. 2012) using package Move for R (Kranstauber and Smolla 2016). Most birds were captured and tagged in late winter, and PTT battery life averaged less than or equal to one year. Therefore, most tags did not capture the fall and early winter period in the year of deployment and captured the fall and early winter the second year post-tagging. Since maximizing understanding of winter movements was a major focus of the study, we calculated separate dbbmm surfaces for each of two winters with at least five days of data and combined these into a weighted mean surface for each animal (as a percentage of the total number of days represented in the surface) with a minimum 30 total combined days of data. We removed any temporal overlap between these datasets (e.g., March 1-15 is represented in only one surface) to minimize biases introduced by overlapping temporal coverage. We used this method of combining multiple seasons for the migration periods as well, but relaxed the requirements for days of data, requiring five days per year and seven total days per period because duration of migration often occurred over a much shorter period. Utilization contour levels of 50, 75, and 95 % were calculated for the mean utilization distribution (UD) surface. The final UD was cropped to the 95% contour for mapping and further analyses. Individual movement models were also saved for analyses of individual home range use and movement.

4.3.9 Arrival and Departure into and out of the Study Area by Sex

We plotted the latitudes of all tagged individuals by date to show latitudinal progression from wintering grounds to breeding grounds, and back. We separated plots by sex, aggregated data into 5-day intervals and calculated mean (± standard deviation) latitudes for each interval.

We generated histograms of the proportion of all animals with active tags south of the northernmost boundary of the BOEM study area (41^{o} N latitude). We used proportion of tagged individuals instead of raw location counts to determine the date of first arrival in fall south of the northern boundary and the last departure in spring north of the study area. We generated histograms for combined and separate sexes.

4.3.10 Use of Lease Areas and Wind Energy Areas

We calculated use of WEAs and Lease Areas by tagged scoters in two ways: 1) as a percentage of overlap of each WEA and Lease Area by the 50% (core use) and 95% (home range) UD areas, and 2) as a percentage of the total 50% (core use) and 95% (home range) UD seasonal distributions area overlapped by the WEA and/or Lease Area. Spatial overlap was determined in R version 3.3.1 (R Core Team 2016) using package raster (Hijmans 2016). Low sample sizes limited our analysis to the aggregate distribution of individuals across all years of the study and available data. Overlap of Lease Areas and/or WEAs and the seasonal distribution of our sample represented a probability (Kie et al 2010) that individuals used the areas during the season, and would have been exposed if turbines were present in those areas, and the % of the entire area that individuals used that was occupied by a WEA and/or Lease Area.

4.3.11 Resource Selection Models

We examined resource selection of Surf Scoters to determine characteristics of preferred habitats that can be used to predict probability of use across the study area. The evaluation of resource preference pertains to the measurement of habitat components an animal *uses* in its environment compared to what is *available* (Johnson 1980). Johnson (1980) identified four hierarchical scales at which animals select resources: (1) first order – the geographic range of the species; (2) second order – the home range of an individual; (3) third order – the habitats used by an individual within its home range; and (4) the individuals resources selected within each habitat. Usage of a resource is defined as the proportion of a resource used by an animal or population over a fixed period of time, while availability refers to the amount that was accessible during that same period of time (Manly et al. 2002). Our first objective was to identify habitat characteristics of the wintering range for each species. For each species, we defined *used* as the pooled telemetry point locations that fell within the 0.95 isopleth of the dbbmm composite winter UD. Used resources are a subset of available resources, and a key factor in resource selection studies is determining the extent of the area that will be included for sampling *available* resources (Buskirk and Millspaugh 2006). We selected the Mid-Atlantic Bight (MAB) as the extent of habitat available for second order resource selection of the wintering home range for each species. The MAB extends from

Nantucket Shoals off southern New England southward to Cape Hatteras off North Carolina. It is bordered by the U.S. coastline on the west and the continental shelf-break on the east. Available points were generated using the *Create Random Points* tool in ArcGIS 10.4.1 (ESRI, Redlands, CA; NOAA 2014b) within the confines of the MAB that was equal to the total number of *used* points for each species.

Our second objective was to determine the habitat characteristics of the core use areas within the home range, which is referred to as a third-order resource selection (Johnson 1980). We defined *used* or core use area as the pooled telemetry point locations that fell within the 0.50 isopleth of the dbbmm composite winter UD. We used a custom script in R version 3.3 (R Core Team 2016) to match each *used* point in the core use area of each animal to two random *available* points generated within the individual's home range. Matching points allowed us to assign certain data associated with the core use point to the random points, including animal ID, sex, date, and time. The selection of telemetry point locations within the 0.50 isopleth for comparison of the habitat characteristics of those points, to points generated within the individual's 0.95 utilization distribution is described in greater detail under sampling protocol-A in Manly et al. (2002).

Habitat characteristics were chosen based on *a priori* knowledge of marine habitat and availability of spatial data within the study area, and included: water depth (m), distance to shore (km), long-term (10-yr winter mean), and mean monthly sea surface temperature (SST; °C), long-term (10-yr winter mean) and mean monthly chlorophyll *a* (mg/m^3), long-term (6-yr winter mean) and mean monthly sea surface salinity (SSS; practical salinity units, PSU), and sediment grain size (mm). We obtained water depth measurements using the NOAA National Geophysical Data Center 3 arc-second Coastal Relief Model for the United States (NOAA 2014a). To estimate distance from shore, we calculated the Euclidean distance between point locations and the nearest segment of the NOAA Medium Resolution Digital Vector Shoreline (1:70,000) using the Near Tool in Arcmap 10.4.1 (ESRI, Redlands, CA; NOAA 2014b). Sediment grain size categories were obtained from the Nature Conservancy's Northwest Atlantic Marine Ecoregional Assessment data portal (https://www.conservationgateway.org). Size categories were grouped by the Nature Conservancy according to correlations with benthic habitat communities. For the dynamic variables with a temporal component, we used Marine Geospatial Ecology Tools to retrieve values for each location based on the date of transmission (Roberts et al. 2010). To measure ocean productivity, we obtained monthly estimates of chlorophyll *a* concentration (mg/m^3) produced by the NASA Goddard Space Flight Center's Ocean Data Processing System. These data had a spatial resolution of 4 km and were derived from radiometric measurements of chlorophyll fluorescence made by the Aqua sensor aboard the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite system (Mueller et al. 2003). Raster and polygon data layers of previously described habitat measurements and animal location data layers were analyzed in ArcGIS 10.2.2. using the WGS 84 spatial projection.

We used the R package, *lme4*, to create generalized linear mixed models, in which animal ID was included as a random effect to allow the intercept to differ between individuals, to explore habitat covariate effects on used versus available locations (Bates et al. 2015, R Core Team 2016). Development of models was exploratory, but, based on *a priori* knowledge of seabird habitat, we predicted that used locations would be related to nine habitat covariates: depth, distance to shore, long-term and seasonal chlorophyll *a*, long-term and seasonal SST, long-term and seasonal SSS, and sediment grain size. Additionally, we tested for the effect of sex on use of winter core areas. Further, based on observed differences in UDs among years, we tested for both the independent effect of year and also as an interactive effect with distance from shore. Differences in distance from shore of winter core use areas and home ranges among years was further examined using the nonparametric Kruskal and Wallis rank sums test in the *PMCMR* package (Pohlert 2014) in R, version 3.3 (R Core Team 2016). Pairwise comparisons between years were also conducted in *PMCMR* using the post-hoc Dunn's test with p-values adjusted with a Bonferroni correction to control for family-wise error rates. Point locations from the winter dbbmm analysis were included in the resource selection models only if complete coverage was available for all the measured habitat characteristics described above. Culling point locations with incomplete coverage, however, generally resulted in the inclusion of fewer individuals in the resource selection analyses (n = 62 for second order and n = 76 for third order) than the number included in the winter dbbmm analyses (n = 78). The difference in sample sizes between the second order and third order analyses is due to the difference in habitat data coverage for the spatial areas under consideration in each analysis. Specifically, the "available" data points in the third order resource selection analysis extend throughout the winter home range while the "available" points in the second order resource selection analysis extend throughout the entire Middle Atlantic Bight. This approach ensured consistency among data sets during the model selection process (described below) for each of the resource selection analysis efforts. Correlations between pairs of continuous habitat variables were quantified using a Pearson product-moment correlation matrix. Multicollinearity among covariates was assessed by calculating variance inflation factors (VIF; Zuur et al. 2009). Covariates with pairwise correlations of < 0.60 and VIF values of < 2.3 were retained as variables in the modeling process. Correlation and VIF results indicated multicollinearity among the following variables: (1) long-term and seasonal SST, (2) long-term and seasonal SSS, and (3) long-term and season chlorophyll *a* concentration. The data were fitted to each singular term to determine the covariate best suited for including in the suite of candidate resource selection models.

We used a nested model approach and candidate models were ranked with Akaike Information Criterion (AIC). The model with the lowest AIC, and those having ΔAIC $\leq$ 2 had the most statistical support, values between 4 and 7 had considerably less support, and those > 10 had virtually no support (Burnham and Anderson 2002). The Akaike weight was also considered when determining the relative amount of statistical support for each model. The importance of the individual explanatory variables in the top nested model were assessed by dropping one term in turn and further comparing AIC values to determine if any variables could be dropped from the model. We estimated confidence intervals for the best-fit population-level RSF model using model-based semiparametric bootstrapping (n = 1,000 iterations) calculated from the bootMer function within the *lme4* package.

4.4 Results

4.4.1 Tagging Summary

A total of 187 Surf Scoters (75 males, 112 females) were tagged during 2011-2015, 108 on wintering areas and 79 during fall near Forestville, Québec (Table 4-2). Overall, we observed a 37% transmitter "loss" rate (this includes known death, known transmitter failure, and undetermined loss) for Surf Scoters with 44% loss for females and 27% loss for males (Table 4-2), reducing the number of individuals used in analyses. Mean tag loss was lowest in 2015; loss for 2011, 2012, 2013, 2014, and 2015 was 45%, 43%, 31%, 42%, and 18% respectively. The Telonics tags used in 2012-2015 were heavier than expected (46-

53 g) compared to the Microwave Telemetry-manufactured tags used in 2011 (38-44 g), and approached the 4-5% of body weight limit recommended (see de Vries 2015). Highest loss (46%) was observed with birds captured during the fall on the St. Lawrence Estuary and the lowest loss (25%) was observed for birds captured during winter on the Chesapeake Bay. Delaware Bay and Pamlico Sound showed similar proportions of tag loss (37% and 33%).

4.4.2 Occurrence and Movement in U.S. Offshore Waters

4.4.2.1 Winter Use and Movements in Study Area

Chesapeake Bay, Pamlico Sound, and Delaware Bay were the most heavily used wintering areas. Coastal New Jersey, Long Island Sound, and Nantucket Sound (outside of study area) were also used by all tagged scoters during winter (Figure 4-3a). Both males and females heavily used Chesapeake Bay and Delaware Bay during winter, but females (Figure 4-3b) were more prevalent along coastal New Jersey and within Nantucket Sound during winter. Male Surf Scoters were less dispersed and more concentrated within Pamlico Sound (Figure 4-3c). There were short movements throughout and between bays during winter. For example, a male Surf Scoter marked in Tangier Sound of Chesapeake Bay moved to Delaware Bay and stayed for one duty cycle (at most six days) and then returned to the Chesapeake Bay by the next transmission window. Daily movement between these bays was confirmed during a test of a new tracking technology, GPS-GSM on Surf Scoters, which provided more continuous tracking data than PTTs (chapter 6). However, the majority of the tagged birds stayed within the bay where they were captured until spring migration began.

4.4.3 Migratory Use of Study Area and Migratory Patterns

4.4.3.1 Spring Migration

Spring migration for Surf Scoters generally (more than 75% of implanted birds) follows a northerly coastal route along the eastern seaboard of the USA and Canada with key stopover and staging areas including: Nantucket Shoals; along the Northumberland Strait shore of New Brunswick and Nova Scotia; Chaleur Bay between New Brunswick and Québec; and along the St. Lawrence estuary and north shore of the Gulf of St. Lawrence (Figure 4-4). One notable exception was a male that migrated from the Chesapeake Bay overland through the Great Lakes (in two consecutive years). This male continued transmitting through another spring migration, when it took the Atlantic coast route to the breeding area in central Quebec. Most females moved to their inland breeding locations in the boreal forest zone of Quebec and Labrador (Figure 4-4), with the exception of three females that, after departing spring staging areas, flew overland over southern Québec toward their breeding area west of Hudson Bay. Most instrumented scoters departed wintering areas in mid-April, with the last bird leaving on 11 June (Figure 4-6). There was no difference in timing of departure between males and females, with 5 June being the latest departure for males and 11 June for females (Figure 4-6).

4.4.3.2 Fall Migration

During fall, Surf Scoters departed breeding and/or molting areas and funneled through the St. Lawrence Estuary, with a large proportion of birds stopping over (staying on average < 10 days; SDJV 2015) on the Nantucket Shoals area, before migrating further south to the wintering areas (Figure 4-5). Key fall staging (staying >14 days; SDJV 2015) areas include the St. Lawrence Estuary and Northumberland Strait coast of New Brunswick and Nova Scotia, and Nantucket Shoals. One individual that migrated overland through the Great Lakes (see Spring Migration above) and molted in James Bay was tracked for two fall migrations and used the Atlantic coastal route to return to the wintering area in both years. The earliest arrival date for scoters to the study area was 14 October with the majority of our tagged birds arriving in November (Figure 6). Both males and females arrived during this time frame with no apparent disparity between them (first male arrived 14 October; first female arrived 20 October; Figure 4-6).

4.4.3.3 Use of Lease Areas and Wind Energy Areas

Overall there was minimal use of the current WEAs and Lease Areas by Surf Scoters with a few exceptions off Massachusetts. One hundred percent of the Cape Wind Energy Area (MA OCS-A 0478) overlapped with Surf Scoter home range (95% UD) during portions of all seasons, and the Massachusetts Lease Areas (OCS-A 500 to 503) overlapped substantially during fall and spring migrations (Table 4-3). The New York and New Jersey Wind Energy Areas were also overlapped, particularly during spring migration (Table 4-3). Only the Cape Wind Energy Area overlapped with the Surf Scoter core use area (50% UD), and solely during spring, when 100% of the Lease Area overlapped (Table 4-4). Results showed that Surf Scoters on spring migration had the highest exposure potential to offshore wind from coastal New Jersey to Nantucket, Massachusetts (Tables 4-3 and 4-4). Potential exposure declined southward along the mid-Atlantic coast during migrations. Bays and nearshore habitats were utilized more during winter (Figure 4-7).

Despite the overlap of some WEAs and Lease Areas with scoter distributions, particularly during winter and spring migration, this overlap represented only a very small percentage of the total area of the scoter home range (< 0.9% and < 0.7% respectively during these periods; Table 4-3). Overlap made up even a smaller percentage of scoter home range during fall migration (< 0.2% Table 4-3). The minimal overlap of scoter core use area (overlap only occurred during spring migration) accounted for < 0.37% of the total scoter core use area (Table 4-4). This indicates that current WEAs and Lease Areas have a relatively small footprint compared with the entire UDs of scoters.

4.4.4 Factors Influencing Occurrence

4.4.4.1 Home Range Area Selection

AIC model selection results indicated that the top supported second order resource selection model predicting Surf Scoter selection of winter home range areas within the MAB included all selected habitat covariates (Table 4-5). The intercept is -39.6 and the scaled beta coefficients, which allow for direct comparison of the strength of the effect of covariates with different measurement units, confirmed that water depth had the strongest effect on the selection of a winter home range relative to the other variables in the model, followed by distance from shore (Table 4-6; Figures 4-8 and 4-9). Water depth at Surf Scoter locations within the estimated home range area ranged from 0.6 – 48.1 m, while water depth at randomly generated points throughout the MAB ranged up to 2,598.3 m (Table 4-7). Quasi-complete separation among these predictor variables, however, caused warning messages in the model output. Specifically, all points in water depths > 48 m were in the randomly generated *available* point category (defined as *0* in the logistic model) and all of those in < 48 m were in the *used* home range point category (defined as *1* in the logistic model). There was some degree of overlap for the two outcomes where water depth was < 48 m, hence the *quasi-complete* designation rather than *complete* separation. But, for points >

48 m, water depth perfectly predicted the outcome of a response of *0 in our top supported model*. Similarly, the upper limit of distance from shore for home ranges was 6.43 km, and, while some degree of overlap among the response variables at distances less than 6.43 km occurred, all points greater than distance from shore were perfectly predicted to a response of *0*. Maximum likelihood estimation does not exist mathematically for such situations, resulting in biased coefficients and large standard errors. One option is to remove the offending variables from the model; however, since water depth and distance from shore were not highly correlated in the Surf Scoter dataset and were nearly perfect predictors of their winter home range area selection, we felt it was important not to exclude them from the model. Therefore, we addressed this issue by using the *logistf* package in R to apply Firth's method to our top supported model, which maximizes a penalized likelihood function to adjust for bias in the estimates resulting from quasi- or complete separation (Firth 1993; Heinze et al. 2013; Table 4-6). Coefficients of other variables in the model, including SST10, SSS6, chlor10, and sediment grain size, did not have an issue with separation and are not affected by the bias associated with water depth and distance from shore. Mean distance from shore for *used* Surf Scoter points within the winter home ranges was 6.43 ± 3.48 km compared to 76.48 ± 52.39 km for *available* point randomly generated throughout the MAB (Table 4-7). Long-term mean winter SST (SST10) had a much smaller effect on home range selection compared to water depth (Table 4-6). Each 1°C increase in SST10 was associated with a 60% decrease in home range area selection within the MAB (Table 4-6; Figure 4-10). SST10 in Surf Scoter winter home ranges were associated with colder temperature and ranged from approximately 4°C to 8°C, whereas SST10 throughout the MAB ranged from 4°C to 21°C (Table 4-7). Conversely, Surf Scoter winter home ranges were associated with higher long-term mean winter chlorophyll *a* concentrations (CHLOR10; $\bar{x}$ = 11.77 mg/m^3) compared to other areas of the MAB $\bar{x}$ = 1.91 mg/m^3; Table 4-7). Each 1 mg/m^3 increase in CHLOR10 at point location was associated with a 3.5 fold greater odds of that point being in a Surf Scoter winter home range (Table 4-6; Figure 4-11). Surf Scoter winter home ranges were associated with lower saline concentrations compared to other areas in the MAB (Table 4-7). Indeed, each one unit (psu) increase in long-term mean sea surface salinity (SSS6) was associated with a 40% decrease in the probability of winter home range area selection (Table 4-6; Figure 4-12). Areas within the MAB with sediment in any of the sand and gravel categories were more likely to be within Surf Scoter winter home ranges than areas with sediment in the silt/mud (0.00 – 0.03 mm) grain size category (Table 4-6). Among used locations within the winter home range, the 0.17 – 0.35 mm sand grain size category occurred most frequently with 54% of locations having that sediment type (Figure 4-13). Indeed, locations with sediment comprised of the sand (0.17 – 0.35 mm) grain size category were 3.5 times more likely to be within SUSC winter home range compared to the silt/mud category (Table 4-6). These increased odds are all relative to the silt/mud category. However, sediment grain size was generally not a strong predictor of winter home range selection (Figure 4-14).

4.4.4.2 Core Use Area Selection

The top supported third order resource selection model predicting Surf Scoter winter core use site selection within their home ranges included water depth, long-term mean winter SST, long-term mean winter chlorophyll *a*, distance from shore, and year effects (Table 4-8). The intercept is -0.91 with a variance of 0.24 associated with the random effect for animal; the intra-class correlation among habitat characteristics found at locations of the same individual was 0.07 (Table 4-9). Probability of selection for core use areas decreased 50% with each 1 m increase in water depth (Table 4-9; Figure 4-15). Mean water depths averaged $\bar{x}$ = 7.15 ± 4.79 m in core use areas compared to $\bar{x}$ = 10.10 ± 7.43 m for the home range

(Table 4-10). Core use sites were associated with colder long-term mean winter SST (°C) and each 1°C increase was associated with a 20% decrease in the probability of core use site selection (Table 4-9; Figure 4-16). Long-term mean winter SST in core use areas was $\bar{x}$ = 5.85 ± 2.24°C compared to a home range mean of $\bar{x}$ = 6.09 ± 2.41°C (Table 4-10). Long-term mean winter chlorophyll *a* (mg/m^3) concentrations had a modest effect on core use site selection with each 1 (mg/m^3) increase associated with an 11% increase in probability of core use site selection (core use areas: $\bar{x}$ = 12.59 ± 4.56 (mg/m^3); home range: $\bar{x}$ = 11.95 ± 5.58 (mg/m^3; Figure 4-17, Tables 4-9 and 4-10). The effect of distance from shore on core use site selection varied between years. Relative to the winter of 2011-2012, distance from shore had the strongest effect on core use site selection during the winter of 2012-2013 and the weakest effect during the 2013-2014 winter period (Table 4-9). Indeed, probability of core use site selection decreased by 25% with each 1 km increase in distance from shore during the 2012-2013 winter season, whereas probability of use decreased by only 11% with increasing distance from shore the following year (Figure 4-18). The nonparametric Kruskal and Wallis one-way analysis of variance by ranks test results indicated a significant difference in distance from shore of core use areas among years. Pairwise comparisons indicated that core use areas during the winter of 2012 to 2013 were closer to shore compared to all other winters at $\bar{x}$ = 4.02 ± 2.93 km (Table 4-11; Figure 4-19). Results also revealed that core use areas during the winter of 2014-2015 were significantly farther offshore compared to all other winter periods at $\bar{x}$ = 5.47 ± 3.18 km ($P < 0.005$), with the exception of 2011 – 2012 winter period (Table 4-11, Figure 4-19). Overall home range areas were also significantly farther offshore during the winter of 2014-2015 at 7.10 ± 4.90 km compared to all other years, including the 2011 – 2012 winter period ($P < 0.001$; Table 4-11, Figure 4-20).

4.5 Discussion

European research suggests that wind development may influence Surf Scoters in the Atlantic in the following ways: 1) potential mortality caused by collisions with turbines; 2) creation of barriers to movement of birds, thereby, increasing energy costs and displacing birds from foraging habitat; and 3) creation of artificial reef habitat with epibenthic fauna (Drewitt and Langston, 2006; Masden et al. 2010, Furness et al. 2013, Dierschke et al. 2016). PTT-marked Surf Scoters wintering and migrating along the Atlantic coast exhibited significantly higher use of nearshore habitats with minimal exposure to potential wind farms in the offshore habitat except for the northern proposed wind energy areas. Goyert et al. (2016) noted that Surf Scoters identified during surveys of the mid-Atlantic region were generally in close proximity to nearshore waters and would have higher exposure to future development in mid-Atlantic wind energy areas located closest to shore (DE and MD). Coastal aerial surveys conducted by Silverman et al. (2013) observed the mean distance of Surf Scoters from shore ranged between 5.3 and 7.6 km, depending on the physical characteristics of the coastline. This finding largely corresponds with our resource selection modeling results showing Surf Scoters using habitats 6.43 ± 3.48 km from shore, suggesting minimal overlap in offshore use by scoters with Federal offshore wind energy areas especially with the southern proposed wind energy areas. The greatest potential exposure occurred on spring migration from coastal New Jersey to Nantucket, Massachusetts.

Overall, usage of any single WEA or Lease Area represented a very small fraction of the total of any seasonal distribution of scoter examined in this report (< 0.5% of total home range - 95% UD). Even overlap of all combined WEAs and Lease Areas with scoter distributions made up a small portion of the total for the season with highest overlap (< 0.9% for winter home range - 95% UD). It is important to note, however, that the distributions derived from this study only represent seasonal use by those sampled individuals during the years of our study. Estimates of spatial distribution do not account for inter-annual variability in distribution, differences in use among age-class or sexes, or any of the complex interactions among these variables for the Surf Scoter population as a whole. Furthermore, the observed percentage of WEAs and Lease Areas overlapping UDs within a season may not fully capture how birds are using the space within that entire time period. For example, although a WEA may represent < 0.9% of the home range area, this does not necessarily indicate the rate at which birds transited the WEA, or the proportion of time spent within that WEA. The dbbmm models provide information about the potential for exposure at WEAs and Lease Areas, and do not consider the influence of additional factors contributing to risk, such as flight height and behavior.

It should also be noted that coastal and nearshore wind energy development has been considered from Maine to North Carolina. Wind development in state waters could have significant impact on wintering and migrating Surf Scoters along the Atlantic, especially if they are constructed adjacent to developments in Federal waters, such as coastal waters of New Jersey. Such cumulative effects of facilities constructed in both Federal and adjacent state waters, are not well understood, but are important to consider when determining overall vulnerability of a species to offshore wind development (Goodale and Milman 2014).

As no wind facilities are currently operating in Federal waters, it is unclear how Surf Scoters would react to a facility if encountered. Individuals could fly through wind energy areas, potentially exposing them to turbines, and direct collision mortality. Risk of collision mortality is greatest among marine bird species that spend a high proportion of time flying at the height of turbine blades (Johnston et al. 2014). Offshore turbines generally have tower heights > 65 m and rotor diameters of 76 to 130 m. The maximum height of the structure, at the very tips of the blades, can exceed 200 m. In spite of a small sample size of GPS-GSM-tagged Surf Scoters (*n* = 3), we recorded an average maximum flight altitude of 300.3 ± 122.1 m, which is higher than height of most turbines. However, average daily flight altitudes were 12.9± 13.6 m (see Chapter 6), with individuals at times recorded within turbine blade heights. Therefore, the potential exists for interaction with the turbines. However, data from PTT- and GPS-GSM-tagged (which provided a nearly-continuous record of movements of tagged individuals; see Appendix B) scoters suggests that scoters fly overland during migratory movements. In spite of the small sample size of GPS-GSM-tagged scoters (*n* = 3), we documented Surf Scoters flying over the Delaware Peninsula while transiting between the Chesapeake and Delaware bays during early spring migration, and flying overland from the Bay of Fundy to the Gulf of St. Lawrence later in spring migration. Many scoters (including Black Scoter, *Melanitta americana*) have been observed making high altitude overland flights at night in New Brunswick, Canada as well (Scott Gilliland, pers. comm.). So, it is possible that migrating Surf Scoters could move overland if they encountered offshore wind developments, rather than risking exposure by flying through them.

Several European studies have suggested that scoters and other marine birds avoid wind farms altogether when they are encountered. Dierschke et al. (2016) observed no long-lasting use of offshore wind energy areas by Common Scoters (*Melanitta nigra*), and when they did enter wind facilities, they did so where turbines were inactive (Petersen et al. 2006, Dierschke et al. 2016). Avoidance, however, can produce adverse effects from displacement if it results in additional energetic demands and/or loss of foraging habitat (Guillemette et al. 1998, Petersen et al. 2004). Furness et al. (2013) determined that scoters were more at risk of displacement from Scottish wind farms than most other marine bird species.

Overall post-construction observation of wind energy areas in Europe indicate a variable partial avoidance response by scoters, but are most likely to show population-level effects of loss of foraging habitat as a consequence of displacement by offshore wind energy areas (Dierschke et al. 2016). Foraging sites lost to wind energy development could possibly be compensated by shifting to other available foraging areas, though scoters forage primarily on sessile benthic prey and show strong tenacity to specific bivalve beds (Kaiser et al. 2006); their ability to redistribute is unknown. Topping and Petersen's (2011) modeling of the cumulative impact of disturbance by wind turbines suggests that the impact of these through increased travel distance and habitat loss is trivial, even for species that show especially strong avoidance behavior and have a high displacement ranking.

In addition to potential adverse impacts of offshore wind development on wildlife species, there are possible benefits. Wind development can create changes in the pelagic and benthic fauna (Leonhard and Pedersen 2006, Lindeboom et al. 2011, Reubens et al. 2013, Dierschke et al. 2016). Increases in shellfish attract animals that feed on them, including fish and marine mammals (Wilhelmsson et al. 2006, Lindeboom et al. 2011, Maar et al. 2009, Russell et al. 2014, Bailey et al. 2014). Foundation and scour protections create a new hard substrate on formerly soft bottom, creating an artificial reef, which is rapidly colonized by various epibenthic invertebrates (de Mesel et al. 2013, Gutow et al. 2014). In addition, new sandbanks may develop owing to shifted currents in shallow waters (Perrow et al. 2006), and turbulence at turbines may bring food particles to the surface, where they are available to surface-feeders (Mendel et al. 2013, Dierschke et al. 2016). Common Scoters dive for bivalves within wind farms in Europe (Petersen and Fox 2007, Petersen et al. 2014). Results of modeling efforts predicted seabirds in three wind farms in Normandy to positively respond to biomass aggregations on piles and turbine scour protections (Raoux et al. 2017). Artificial reef habitat formation likely also plays a role in attracting seabirds to offshore hydrocarbon platforms (Burke et al. 2012). Complex and indirect ecosystem effects such as these are extremely difficult to predict and post-construction monitoring is needed for comprehensive understanding (Furness et al. 2013).

While our tracking data showed higher use of bays than offshore areas in winter, we acknowledge the potential that our sample of tagged birds may have been biased by where they were captured. However, comparisons with data from another tracking study, which used different capture areas, verified similar winter and migratory patterns. Sea Duck Joint Venture (2015) deployed transmitters on Surf Scoters captured during fall on the St. Lawrence River, a common staging area. These females also made heavy use of bays and inland areas (with coastal New Jersey being an exception), many within our study area, during winter (Figure 4-21), suggesting that wintering areas used by our sample of female Surf Scoters may be representative of birds tagged in other areas, as well. Silverman et al. (2013) also found high densities of Surf Scoters during aerial surveys in Chesapeake and Delaware Bays and along the Maryland-Delaware coast, with smaller high density areas around Nantucket Island and the southern end of Pamlico Sound

In conclusion, we found that the vast majority of scoters we tagged utilized nearshore habitats during migration and the major bays during winter. Therefore, they had relatively low overlap with potential offshore wind development under consideration in Federal waters of the mid-Atlantic U.S. Tagged Surf Scoter use overlapped more with WEAs and Lease Areas north of our study area near Massachusetts during migratory periods, particularly in the spring. Based on our findings of near-shore use, Surf Scoters could face exposure to near-shore wind facilities in state waters, such as coastal New Jersey, and cumulative exposure could be a concern if wind facilities were constructed adjacent to one another in state and Federal waters. Post-construction monitoring should be conducted to determine if Surf Scoter distributions are altered in response to wind farms. If so, it will be important to study how adaptable the species is to cumulative impacts, and both positive and negative changes in food resource availability.

Table 4-1. Argos locations classes and their assigned errors in meters used in the dynamic Brownian bridge movement models.

Argos location class	Mean error (m)
3	1,500
2	3,300
1	7,600
0	17,200
A	15,000
B	20,900
Z	18,600

Table 4-2. Number of adult Surf Scoters (by sex) marked by site, year, tag failure (lost), and mortality data. “Lost” refers to both mortalities and tag failure.

	Chesapeake Bay				**Delaware Bay**			**Pamlico Sound**			**St Lawrence River**		**TOTAL**
	2011	**2012**	**2013**	**2015**	**2013**	**2014**	**2015**	**2011**	**2014**	**2015**	**2012**	**2013**	
Male deployed	16	12	12	6	4	6	4	2	8	5	0	0	75
Female deployed	4	11	4	3	0	3	1	2	4	1	26	53	112
Total deployed	20	23	16	9	4	9	5	4	12	6	26	53	187
Male lost or died >30d	11	9	9	6	3	3	4	2	6	4	0	0	57
Female lost or died >30d	2	4	3	3	0	0	0	1	3	0	14	33	63
Total lost or died >30d	13	13	12	9	3	3	4	3	9	4	14	33	120
Male died ≤ 30d	5	3	3	0	1	2	0	0	1	1	0	0	16
Female died ≤ 30d	1	4	1	0	0	3	1	1	1	1	3	15	31
Male lost ≤ 30d	0	0	0	0	0	1	0	1	0	0	0	0	1
Female lost ≤ 30d	1	0	0	0	0	0	0	0	0	0	9	5	15
Male lost or died ≤ 30d	5	3	3	0	1	3	0	0	1	1	0	0	17
Female lost or died ≤ 30d	2	4	1	0	0	3	1	1	1	1	12	20	46
Total lost or died ≤ 30d	7	7	4	0	1	6	1	1	2	2	12	20	63
Male missing data	0	0	0	0	0	0	0	0	1	0	0	0	1
Female missing data	0	3	0	0	0	0	0	0	0	0	0	0	3
Total missing data	0	3	0	0	0	0	0	0	1	0	0	0	4
% M lost or died ≤ 30d	31	25	25	0	25	50	0	0	12	20	0	0	23
% F lost or died ≤ 30d	50	36	25	0	0	100	100	50	25	100	46	38	41
% Total lost or died ≤ 30d	35	30	25	0	25	67	20	25	17	33	46	38	34

Table 4-3. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 95% “home range” utilization distribution (UD) of adult Surf Scoters on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (UD area in sq. km)	**Fall migration (35,6994.6)**		**Winter (26,537.2)**		**Spring migration (72,4841.4)**	
WEA/Lease Names (area in sq. km)	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**
MA OCS-A 0478 (119.1)	100	0.03	100	0.45	100	0.02
RI / MA OCS-A 0486 (394.6)	2.89	0	0	0	100	0.05
MA OCS-A 0501 (675.6)	38.15	0.07	0	0	100	0.09
MA OCS-A 0500 (759.0)	24.14	0.05	0	0	100	0.1
RI / MA OCS-A 0487 (272.2)	0	0	0	0	100	0.04
MA OCS-A 0502 (1004.1)	1.88	0.01	0	0	100	0.14
MA OCS-A 0503 (569.1)	0	0	0	0	100	0.08
NY Proposed Commercial Lease Unsolicited (165.6)	0	0	0	0	100	0.02
NY OCS-A 0512 (321.2)	0	0	0	0	100	0.04
NJ OCS-A 0499 (742.1)	0	0	3.75	0.1	20	0.02
NJ OCS-A 0498 (649.9)	0	0	0	0	0	0
DE OCS-A 0482 (390.5)	0	0	19.97	0.29	0	0
MD OCS-A 0489 (132.6)	0	0	0.19	0	0	0
MD OCS-A 0490 (190.2)	0	0	0	0	0	0
VA OCS-A 0483 (456.8)	0	0	0	0	0	0
VA OCS-A 0497 (8.6)	0	0	0	0	0	0
NC OCS-A 0508 (495.8)	0	0	0	0	0	0
SC Call Area - Grand Strand (2673.1)	0	0	0	0	0	0
NC WEA - Wilmington West (208.6)	0	0	0	0	0	0
NC WEA - Wilmington East (540.1)	0	0	0	0	0	0
SC Call Area - Cape Romain (652.4)	0	0	0	0	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	5.11	0.17	1.95	0.85	38.34	0.61

Table 4-4. The percent overlap of each of the Federally-designated Wind Energy Areas (WEAs) and Lease Areas with 50% "core use" utilization distribution (UD) of adult Surf Scoters on the U.S. Atlantic coast, and the total area (km^2) overlapped.

Season (Core area in sq. km)	**Fall migration (7,702.1)**		**Winter (6,607.8)**		**Spring migration (31,837.2)**	
WEA/Lease Names (area in sq. km)	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**	**% WEA/Lease Area w/in UD**	**% of total UD area overlapped**
MA OCS-A 0478 (119.1)	0	0	0	0	100	0.37
RI / MA OCS-A 0486 (394.6)	0	0	0	0	0	0
MA OCS-A 0501 (675.6)	0	0	0	0	0	0
MA OCS-A 0500 (759.0)	0	0	0	0	0	0
RI / MA OCS-A 0487 (272.2)	0	0	0	0	0	0
MA OCS-A 0502 (1004.1)	0	0	0	0	0	0
MA OCS-A 0503 (569.1)	0	0	0	0	0	0
NY Proposed Commercial Lease Unsolicited (165.6)	0	0	0	0	0	0
NY OCS-A 0512 (321.2)	0	0	0	0	0	0
NJ OCS-A 0499 (742.1)	0	0	0	0	0	0
NJ OCS-A 0498 (649.9)	0	0	0	0	0	0
DE OCS-A 0482 (390.5)	0	0	0	0	0	0
MD OCS-A 0489 (132.6)	0	0	0	0	0	0
MD OCS-A 0490 (190.2)	0	0	0	0	0	0
VA OCS-A 0483 (456.8)	0	0	0	0	0	0
VA OCS-A 0497 (8.6)	0	0	0	0	0	0
NC OCS-A 0508 (495.8)	0	0	0	0	0	0
SC Call Area - Grand Strand (2673.1)	0	0	0	0	0	0
NC WEA - Wilmington West (208.6)	0	0	0	0	0	0
NC WEA - Wilmington East (540.1)	0	0	0	0	0	0
SC Call Area - Cape Romain (652.4)	0	0	0	0	0	0
SC Call Area – Winyah (141.1)	0	0	0	0	0	0
SC Call Area – Charleston (144.0)	0	0	0	0	0	0
Cumulative %	0	0	0	0	1.03	0.37

Table 4-5. Generalized linear model selection results examining second order resource selection effects of habitat characteristics on the probability of adult Surf Scoter (*n* = 62) winter home range use in the Mid-Atlantic Bight. Habitat variables include: water depth (m; depth); distance from shore (km; dist); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm; SED). Models are ranked according to Akaike Information Criterion (AIC). The table shows the variables included in the model, number of estimated parameters (*K*), differences between model Akaike Information Criterion (ΔAIC), and AIC weights (w_i).

Model	K	AIC	ΔAIC	w_i
depth+SST10+CHLOR10+SSS6+SED	11	4652	0	1
depth+SST10+CHLOR10+SSS6+dist	6	4707	55	0
depth+SST10+CHLOR10+SSS6	5	4928	276	0
depth+SST10+CHLOR10	4	4949	297	0
depth+SST10	3	5575	923	0
depth	2	6247	1595	0
Null model	1	21903	17251	0

Table 4-6. Scaled estimated coefficients (β), odds ratios (OR), confidence intervals (CI), standard errors (SE), and P-values of the effects in the top AIC ranked generalized linear model predicting second order resource selection of adult Surf Scoter (*n* = 62) winter home range within the Mid-Atlantic Bight. Habitat variables include: water depth (m); distance from shore (km); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm).

Habitat Characteristics	Scaled β	OR	CI	SE	P
(Intercept)	-39.6	6.4^{-18}	0.00 – 0.00	1.60	<0.001
Water depth (m)	-89.5	3.8^{-36}	0.00 – 0.00	4.00	<0.001
SST10 (°C)	-0.83	0.44	0.34 – 0.55	0.12	<0.001
CHLOR10 (mg/m^3)	1.24	3.45	3.01 – 3.97	0.07	<0.001
SSS6 (PSU)	-0.43	0.65	0.57 – 0.73	0.06	<0.001
Distance from shore (km)	-6.08	0.002	9.0^{-4} – 0.5^{-3}	0.46	<0.001
Sediment Grain Size					
(0.03 – 0.17 mm) Sand	1.01	2.73	1.84 – 4.06	0.20	<0.001
(0.17 – 0.35 mm) Sand	1.26	3.51	2.39 – 5.14	0.19	<0.001
(0.35 – 0.36 mm) Sand	1.08	2.93	1.91 – 4.51	0.22	<0.001
(0.36 – 0.48 mm) Sand	1.16	3.21	2.09 – 4.90	0.22	<0.001
(0.48+ mm) Gravel	0.56	1.76	1.15 – 2.67	0.21	<0.001

Table 4-7. Comparison of estimated means (SD) of habitat characteristics included in second order resource selection analysis examining adult Surf Scoter (*n* = 62) locations within the winter home range (used) versus random locations within the Middle Atlantic Bight (available). Habitat variables include: water depth (m); distance from shore (km); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm).

	Used		Available	
Habitat Variable	Mean (SD)	Range	Mean (SD)	Range
Water depth (m)	9.19 (4.69)	0.60 – 48.10	416.42 (732.87)	0.10 – 2598.30
Distance from shore (km)	6.43 (3.48)	0.10 – 6.43	76.48 (52.39)	0.10 – 224.79
SST10 (°C)	5.34 (0.72)	4.07 – 7.93	9.42 (3.17)	4.10 – 21.00
CHLOR10 (mg/m^3)	11.77 (4.80)	2.50 – 26.07	1.91 (2.17)	0.30 – 26.07
SSS6 (PSU)	30.40 (1.14)	16.84 – 33.41	33.42 (1.14)	16.86 – 36.31

Table 4-8. Generalized linear mixed model selection results examining the effects of habitat characteristics on the probability of adult Surf Scoter (*n* = 76) third order resource selection of core use areas within the Mid-Atlantic winter home range. Habitat variables include: water depth (m; depth); distance from shore (km; dist); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm; SED). The effect of sex and year were also included, as well as the interactive effect of distance from shore and year. Animal ID was included as a random effect to allow the intercept to vary among individuals. Models are ranked according to Akaike Information Criterion (AIC). The table shows the variables included in the model, number of estimated parameters (K), differences between model Akaike Information Criterion (ΔAIC), and AIC weights (w_i).

Model	K	AICc	ΔAICc	w_i
(1|animal)+depth+sst10+chlor10+dist*year	14	40248.4	0.00	0.64
(1|animal)+depth+sst10+chlor10+dist*year+sex	15	40249.5	1.11	0.36
(1|animal)+depth+sst10+chlor10+dist	6	40300.6	52.18	0.00
(1|animal)+depth+sst10+ chlor10+dist+year	10	40302.6	54.15	0.00
(1|animal)+depth+sst10+ chlor10+dist+sex	7	40302.6	54.18	0.00
(1|animal)+depth+sst10+chlor10	5	40379.1	130.72	0.00
(1|animal)+depth+sst10	4	40419.4	170.94	0.00
(1|animal)+depth	3	40556.2	307.78	0.00
(1|animal)	2	42417.9	2169.53	0.00
Null model	1	42630.7	2382.31	0.00

Table 4-9. Scaled estimated coefficients (β), odds ratios (OR), confidence intervals (CI), standard errors (SE), and P-values of the fixed effects in the top AIC-ranked generalized linear mixed model predicting third order resource selection of adult Surf Scoter (*n* = 76) core use areas within the Mid-Atlantic winter home range. Habitat variables include: water depth (m); distance from shore (km); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm). The effect of sex and year were also included, as well as the interactive effect of distance from shore and year. Animal ID was included as a random effect to allow the intercept to vary among individuals and results shown include: between-animal-variance (τ_{00}); the number of individuals included in the model (N_{animal}); and the intraclass correlation among habitat measurements at locations of the same animal (ICC_{animal}).

Fixed Effects	Scaled β	OR	CI	SE	P
(Intercept)	-0.91	0.50	0.40 – 0.62	0.13	<0.001
Water depth (m)	-0.65	0.56	0.54 – 0.59	0.02	<0.001
Long-term mean winter SST (°C)	-0.33	0.80	0.76 – 0.84	0.02	<0.001
Long-term mean winter chlorophyll *a* (mg/m^3)	0.08	1.11	1.07 – 1.15	0.02	<0.001
Distance from shore (km)	0.005	0.96	0.89 – 1.04	0.04	0.300
Distance from shore (km)*Winter 2012 to 2013	-0.42	0.75	0.68 – 0.83	0.05	<0.001
Distance from shore (km)*Winter 2013 to 2014	-0.15	0.89	0.81 – 0.99	0.05	0.013
Distance from shore (km)*Winter 2014 to 2015	-0.32	0.81	0.73 – 0.90	0.05	<0.001
Distance from shore (km)*Winter 2015 to 2016	-0.23	1.05	0.95 – 1.16	0.05	0.353
Random Effect					
$\tau_{00, animal}$			0.235		
N_{animal}			76		
ICC_{animal}			0.067		

Table 4-10. Comparison of estimated means (SD) of habitat characteristics included in the third order resource selection analysis examining habitat characteristics at adult Surf Scoter (*n* = 76) locations in winter core use (0.50) and home range (0.95) areas. Habitat variables include: water depth (m); distance from shore (km); long-term sea surface temperature (°C; SST10); long-term chlorophyll (mg/m^3; CHLOR10); long-term sea surface salinity (PSU; SSS6); and sediment grain size (mm).

	Utilization Distribution Isopleth	
Habitat Variable	0.50	0.95
Mean monthly chlorophyll *a* (mg/m^3)	10.93 (7.52)	10.80 (8.73)
10-yr mean winter chlorophyll *a* (mg/m^3)	12.59 (4.56)	11.95 (5.58)
Mean monthly SST (°C)	9.61 (4.07)	9.51 (4.04)
10-yr mean winter SST (°C)	5.85 (2.24)	6.09 (2.41)
Mean monthly SSS (PSU)	30.74 (4.38)	31.91 (2.84)
6-yr mean winter SSS (PSU)	30.55 (4.36)	31.81 (2.81)
Distance from shore (km)	4.78 (3.43)	6.25 (4.92)
Water depth (m)	7.15 (4.79)	10.10 (7.43)

Table 4-11. Distance from shore (km) measurements included in the third order resource selection analysis examining year effects on adult Surf Scoter (*n* = 76) locations in the winter core use (0.50 utilization distribution; UD) and home range (0.95 UD) areas.

	Distance from Shore (km)					
	Mean ± SD		Median		Range	
Winter Period	0.50	0.95	0.50	0.95	0.50	0.95
2011 to 2012	5.13 ± 3.87	6.41 ± 5.32	3.76	5.20	0.10 - 25.03	0.10 - 46.89
2012 to 2013	4.02 ± 2.93	5.61 ± 4.02	3.01	4.81	0.10 - 16.63	0.10 - 36.70
2013 to 2014	4.56 ± 3.38	6.01 ± 4.94	3.58	4.94	0.10 - 16.65	0.10 - 54.10
2014 to 2015	5.47 ± 3.18	7.10 ± 4.90	5.10	6.51	0.14 - 15.89	0.10 - 30.50
2015 to 2016	5.31 ± 3.80	6.63 ± 5.58	3.98	4.05	0.14 – 16.67	0.10 - 30.95

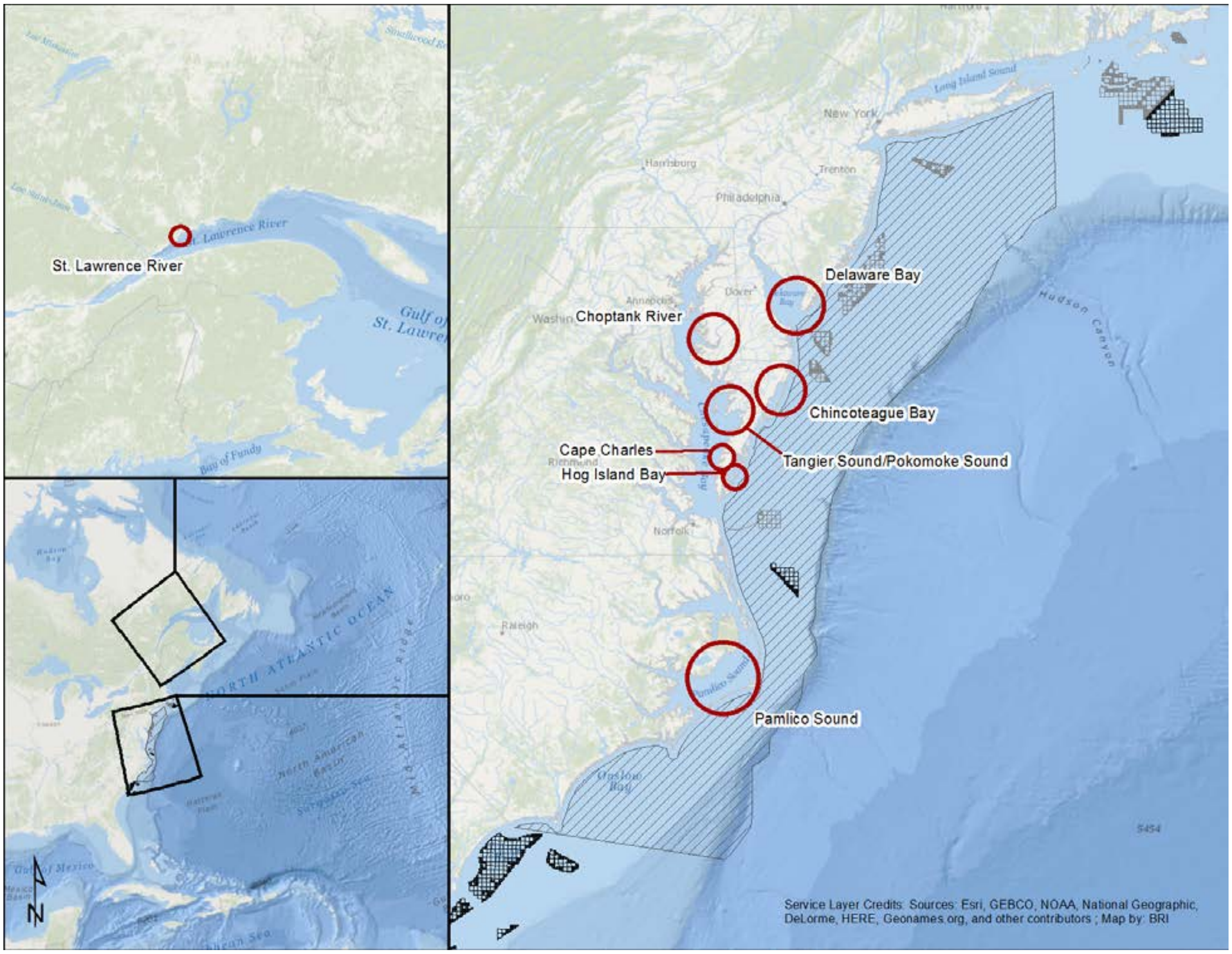


Figure 4-1. Study area (grey hashed polygon) covering Federal waters (≥ 5.6 km) from the southern coast of Long Island, NY to the southern border of NC. This area contains six proposed wind energy areas (grid polygons). Captures and tagging occurred during winter at sites across the study area where large concentrations of wintering Surf Scoters were observed or documented by researchers and hunters during prior years. An additional capture effort occurred during migration on the St. Lawrence River by our Sea Duck Joint Venture partners (upper left map).

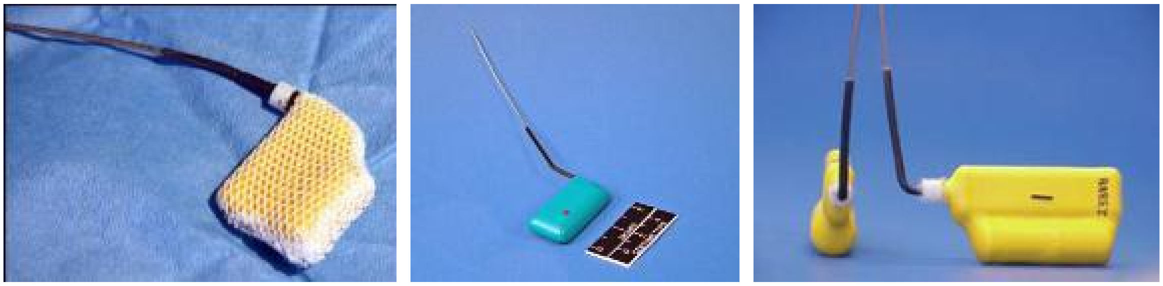


Figure 4-2. Left: PTT prepared with sterile mesh for implantation in Surf Scoter. Center and right: Two antennae configurations of pressure proofed implantable PTTs.

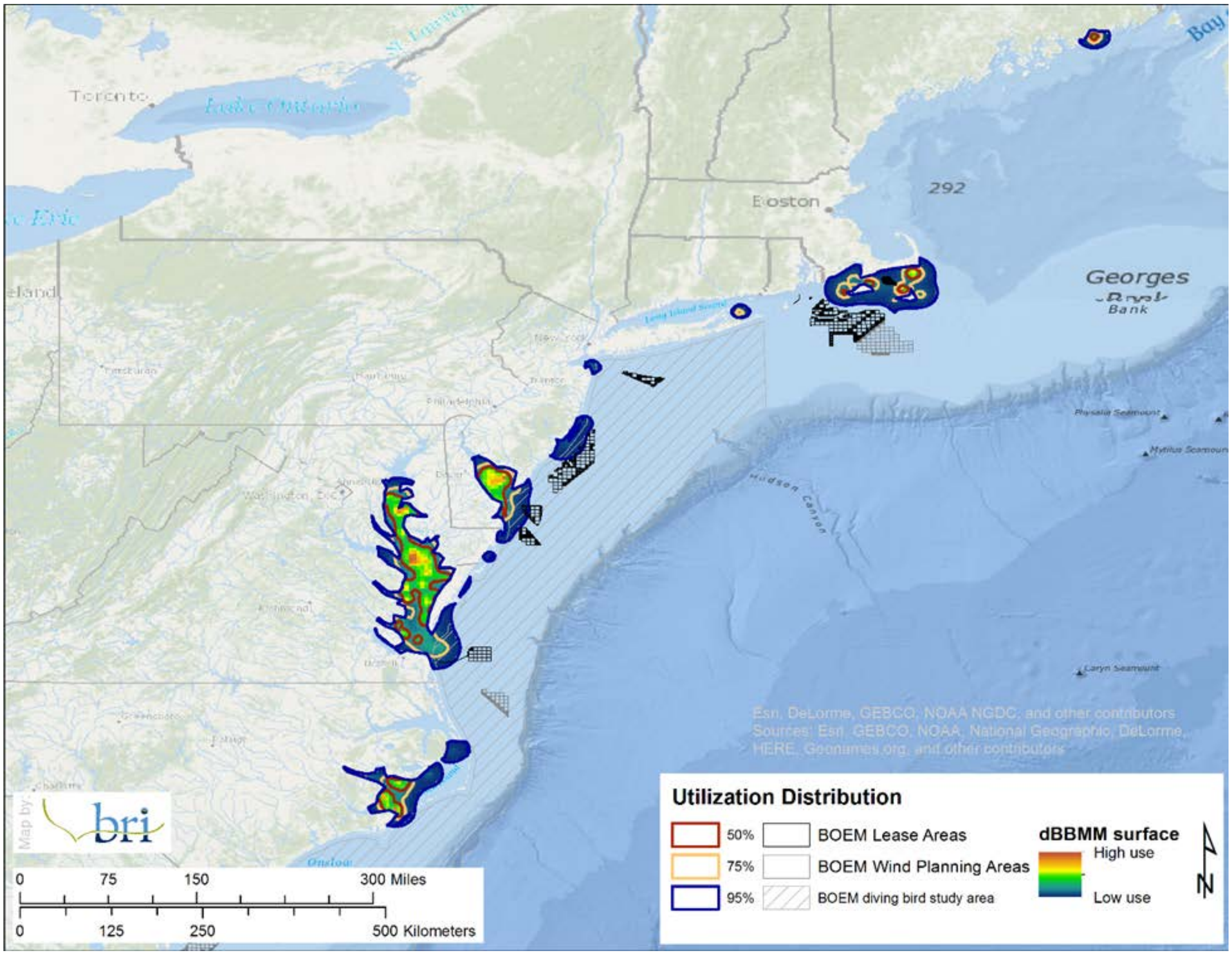


Figure 4-3a. The winter utilization distributions (UDs) of all satellite-tagged adult Surf Scoters for which sufficient data were available (*n* = 78) in the Mid-Atlantic study area (hatched) 2011 - 2015, including the mean winter home range (95% UD, blue) and core use areas (50% UD, red).

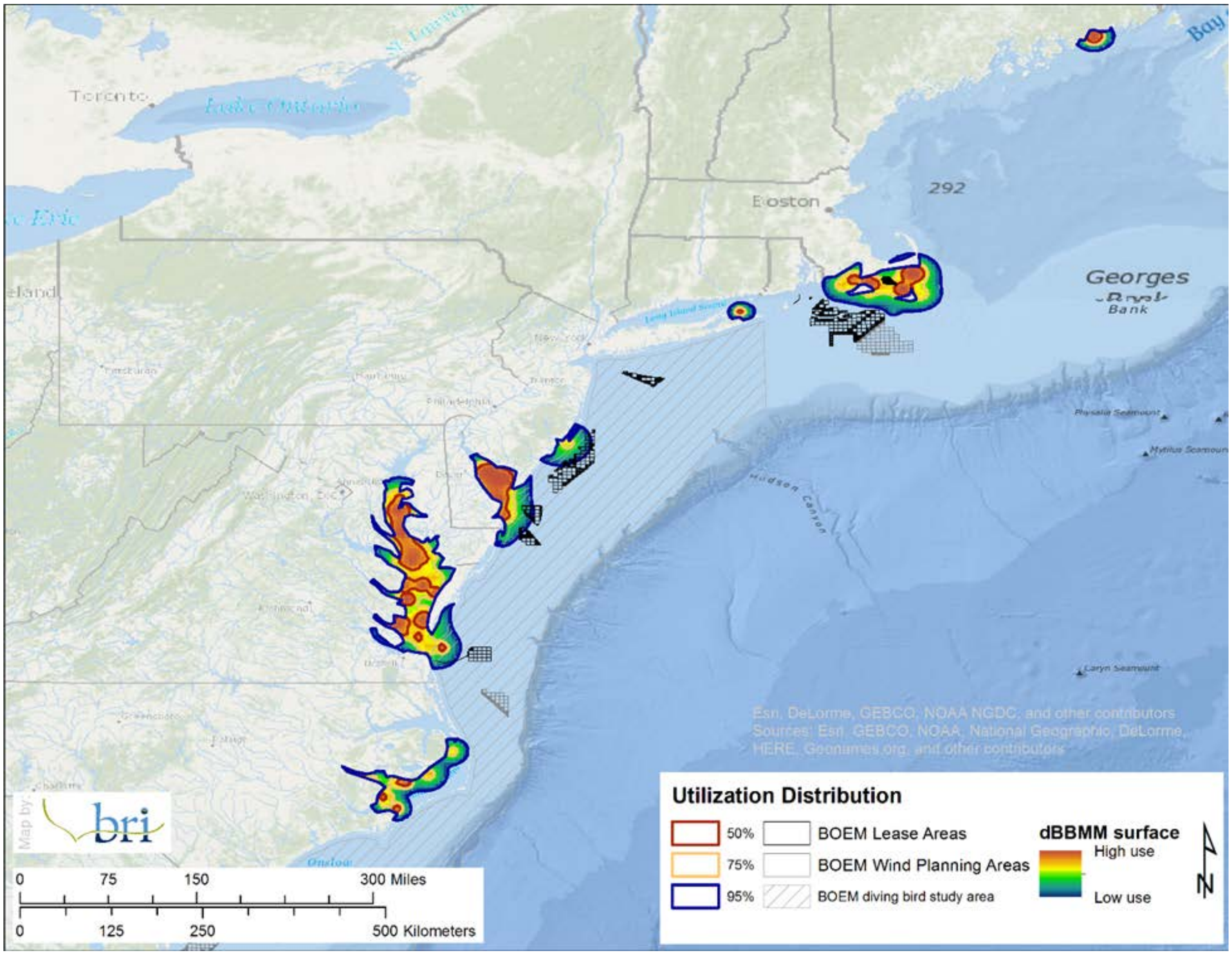
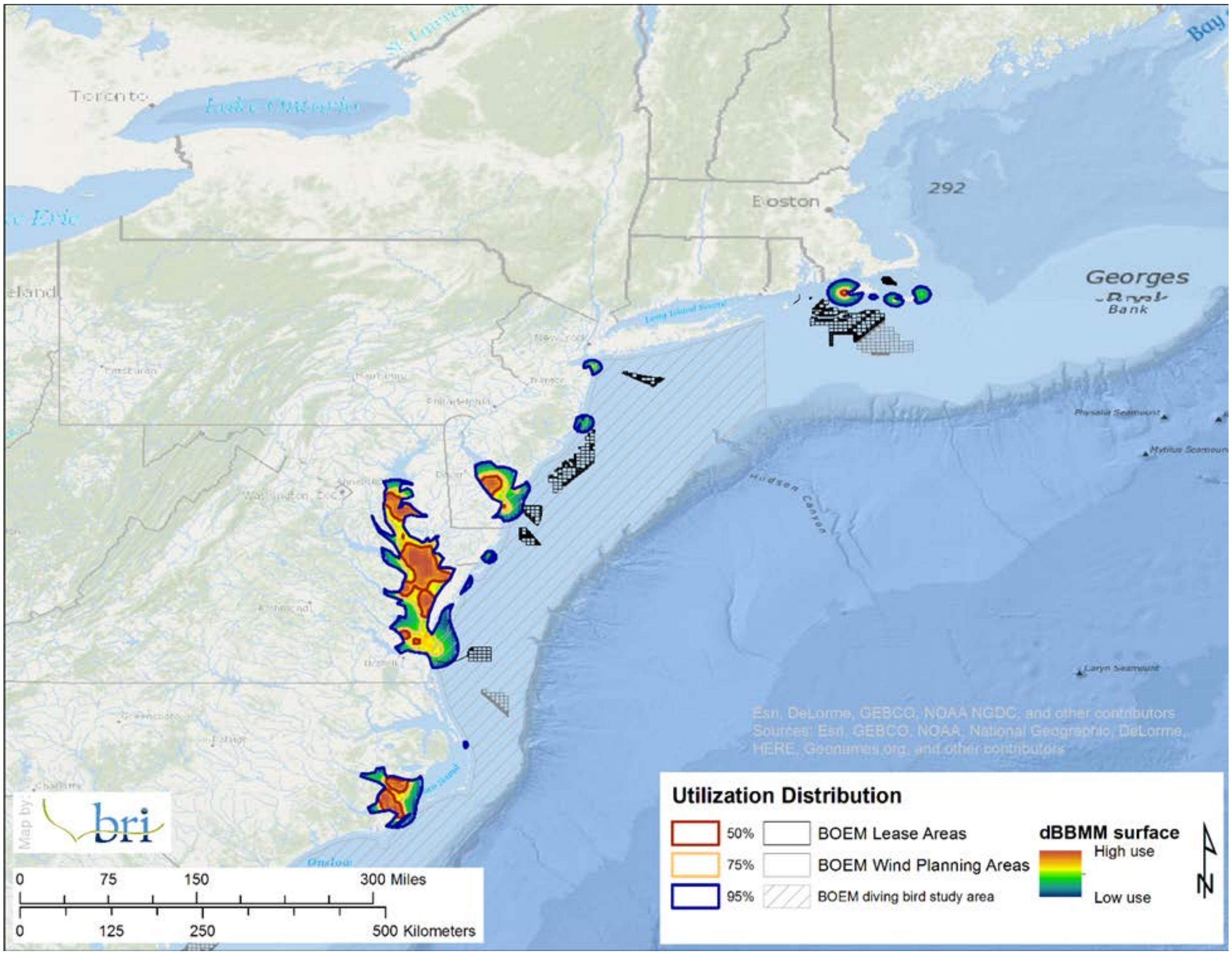


Figure 4-3b. The winter utilization distributions (UDs) of all adult female satellite-tagged Surf Scoters for which sufficient data were available (*n* = 37) in the Mid-Atlantic study area (hatched) 2011 - 2015, including the mean winter home range (95% UD, blue) and core use areas (50% UD, red).



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 4-3c. The winter utilization distributions (UDs) of all adult male satellite-tagged Surf Scoters for which sufficient data were available (*n* = 41) in the Mid-Atlantic study area (hatched) 2011 - 2015, including the mean winter home range (95% UD, blue) and core use areas (50% UD, red).

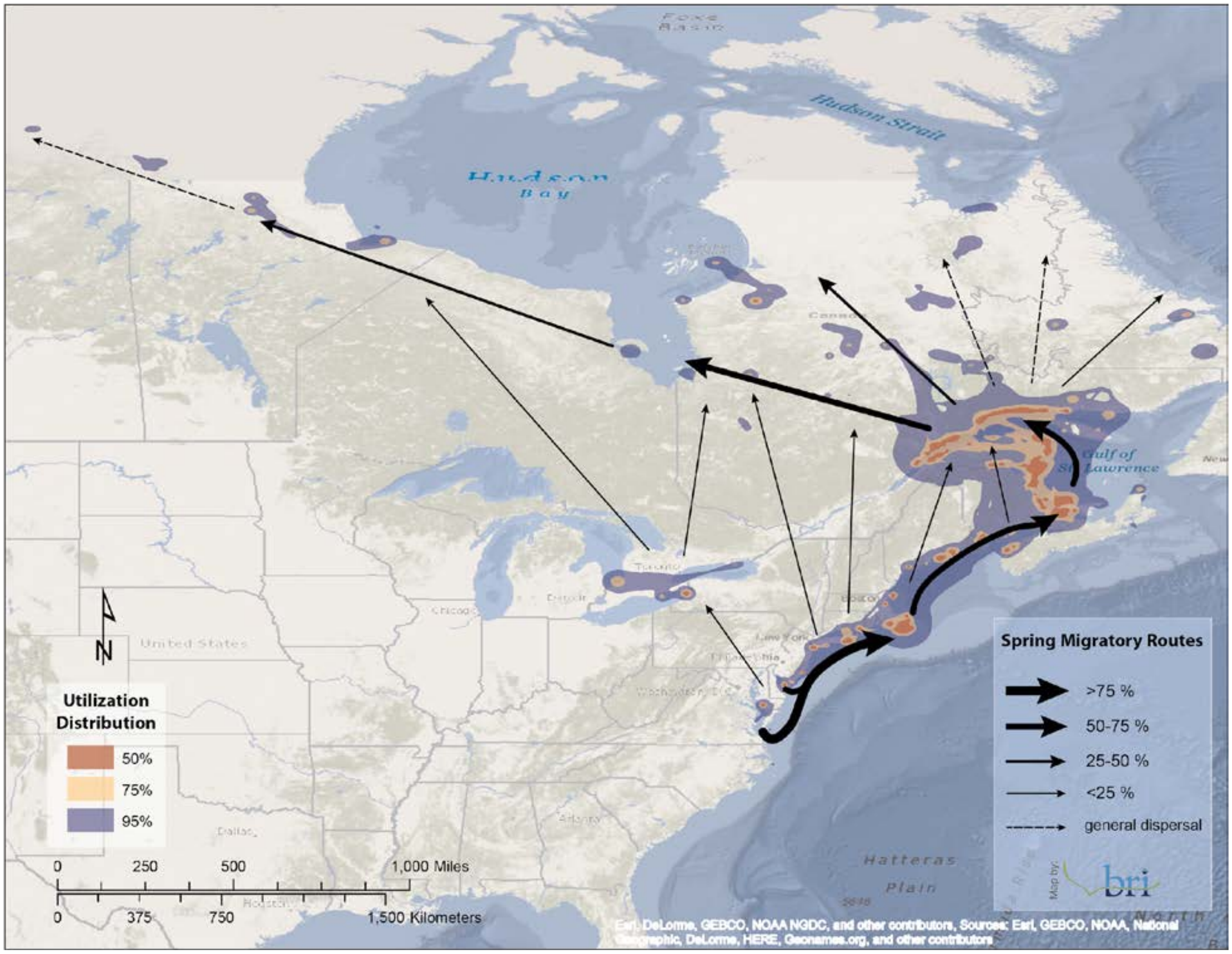
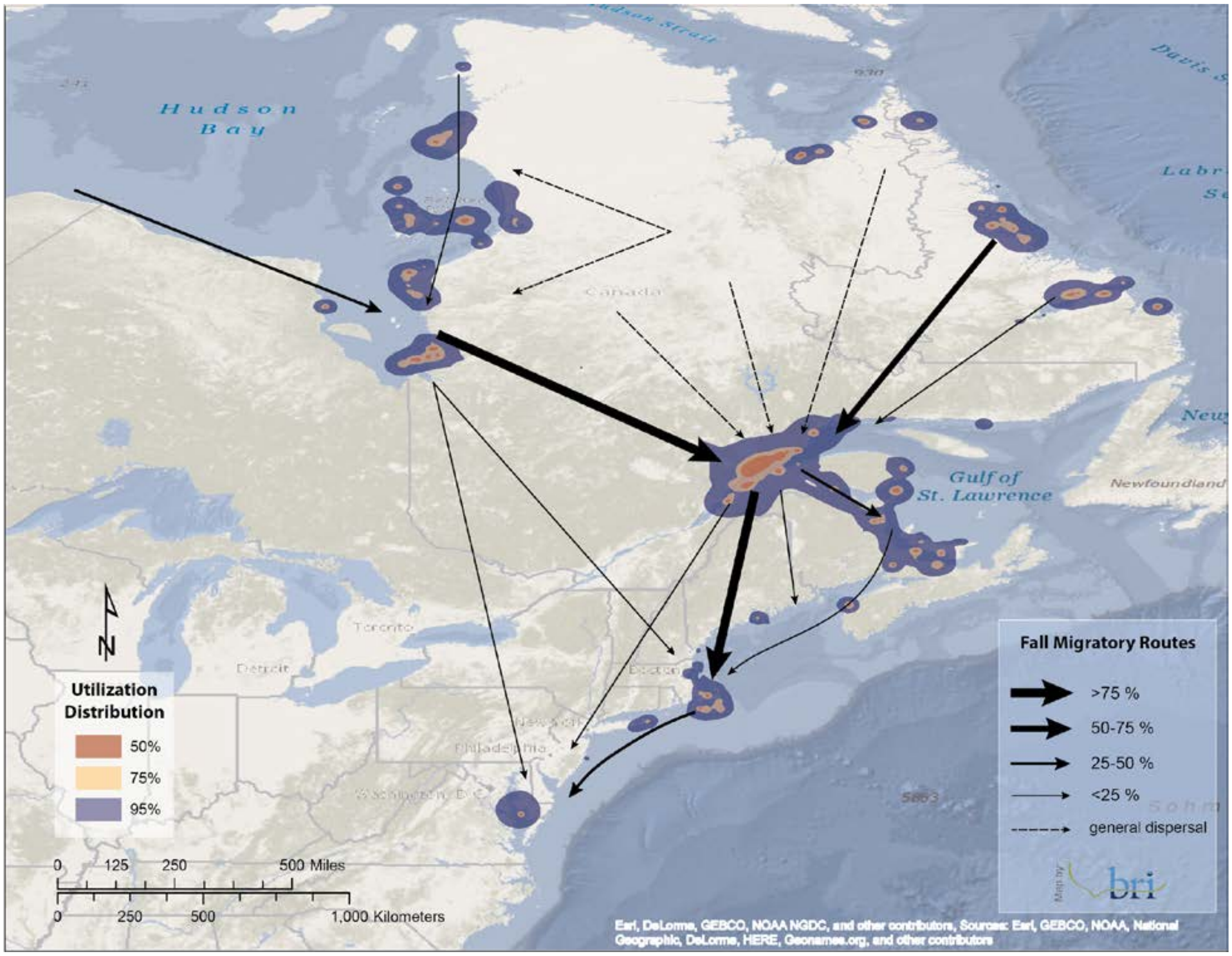


Figure 4-4. Spring migration routes for adult male (*n* = 47) and adult female (*n* = 40) Surf Scoters for which sufficient data were available marked during winter along the mid-Atlantic coast.



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors, Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 4-5. Spring migration routes for adult male (*n* = 36) and adult female (*n* = 47) Surf Scoters for which sufficient data were available marked during winter along the mid-Atlantic coast.

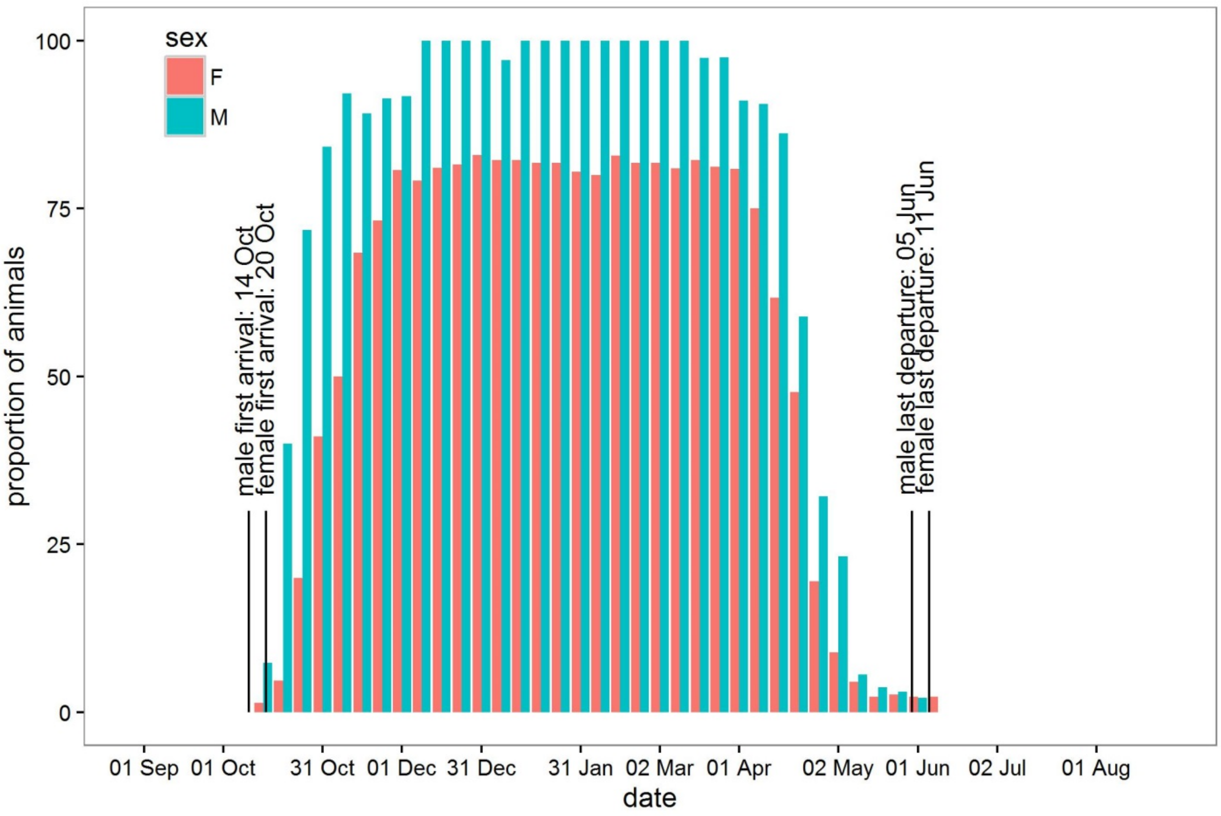


Figure 4-6. Proportion of all adult tagged Surf Scoters in the study area by sex and date, including dates of first arrivals and last departures.

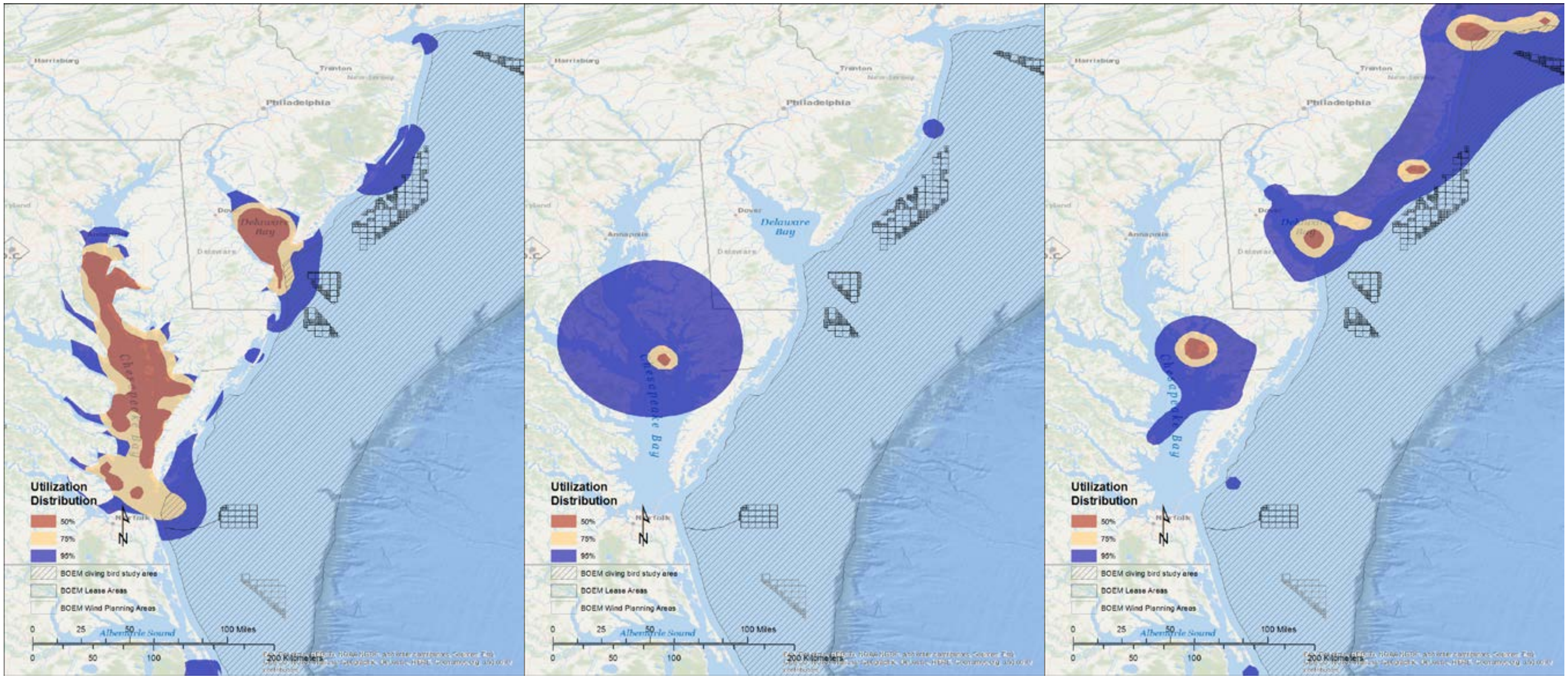


Figure 4-7. Dynamic Brownian bridge movement modeling (dbbmm) utilization distributions (50%, 75%, and 95%) for adult Surf Scoters during winter (left; *n* = 78), fall migration (middle; *n* = 83), and spring migration (right; *n* = 87). Surf Scoters exhibited minimal overlap with proposed wind energy areas (grid polygons) in federal waters during winter and spring migration, and no overlap during fall migration.

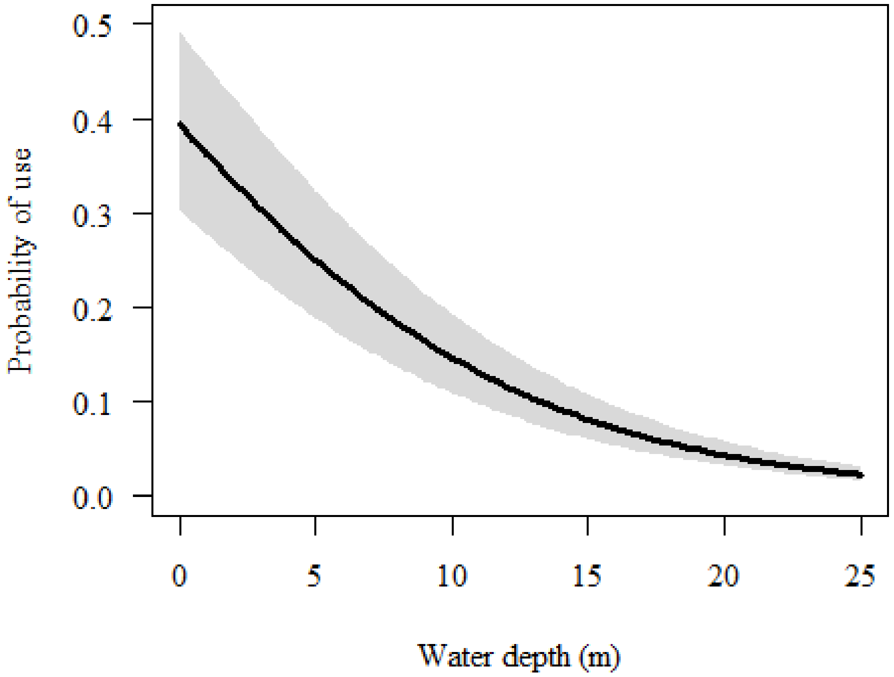


Figure 4-8. Generalized linear model results of the effect of water depth on probability of adult Surf Scoter (*n* = 62; 28 females, 34 males) second order resource selection of the winter home range within in the Mid-Atlantic Bight.

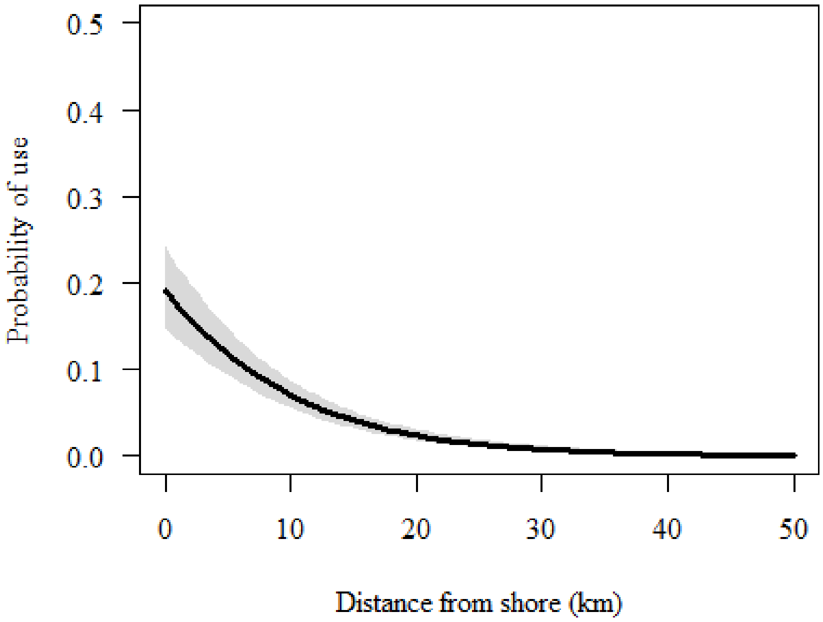


Figure 4-9. Generalized linear model results of the effect of distance from shore (km) on probability of second order resource selection of the adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range within the Mid-Atlantic Bight.

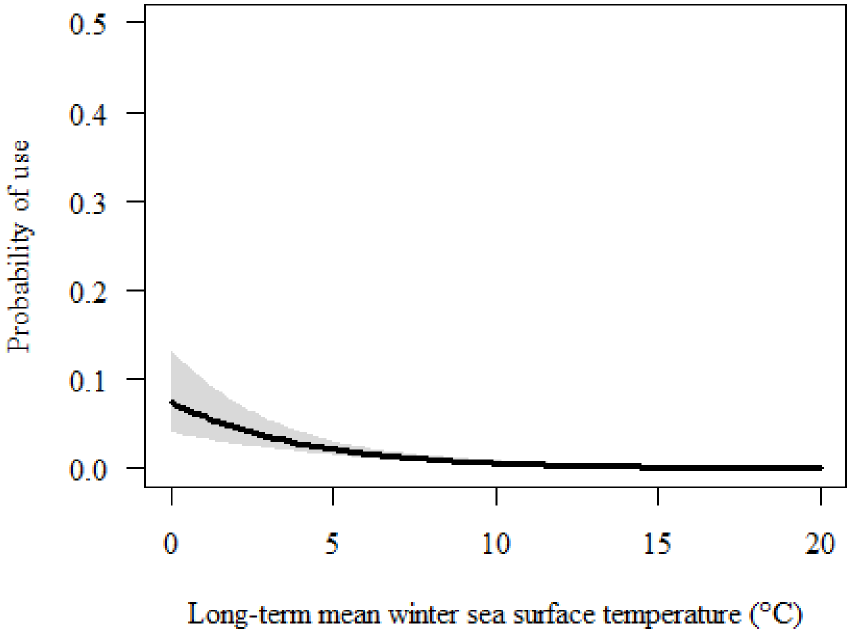


Figure 4-10. Generalized linear model results of the effect of long-term sea surface temperature (SST10; °C) on probability of second order resource selection of the adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range within the Mid-Atlantic Bight.

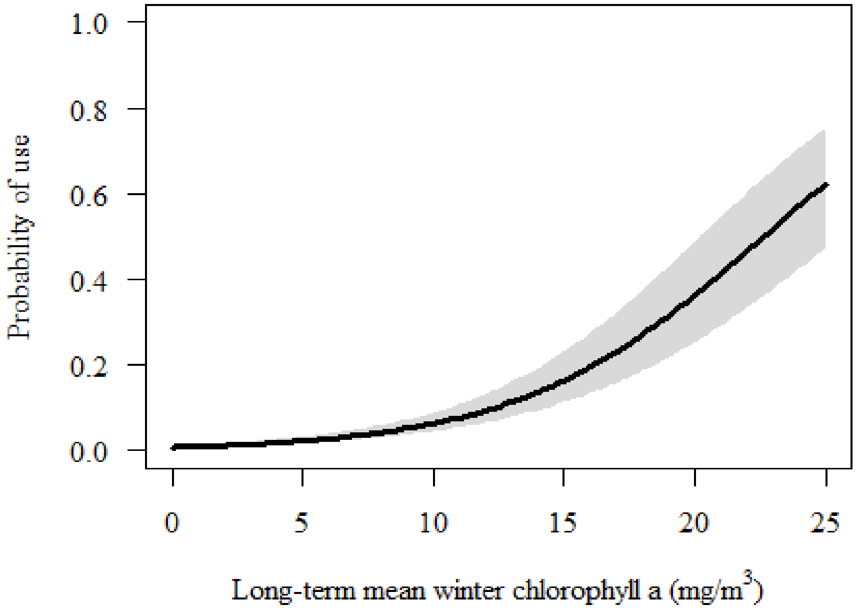


Figure 4-11. Generalized linear model results of the effect of long-term chlorophyll *a* concentrations (CHLOR10; mg/m^3) on probability of second order resource selection of adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range within the Mid-Atlantic Bight.

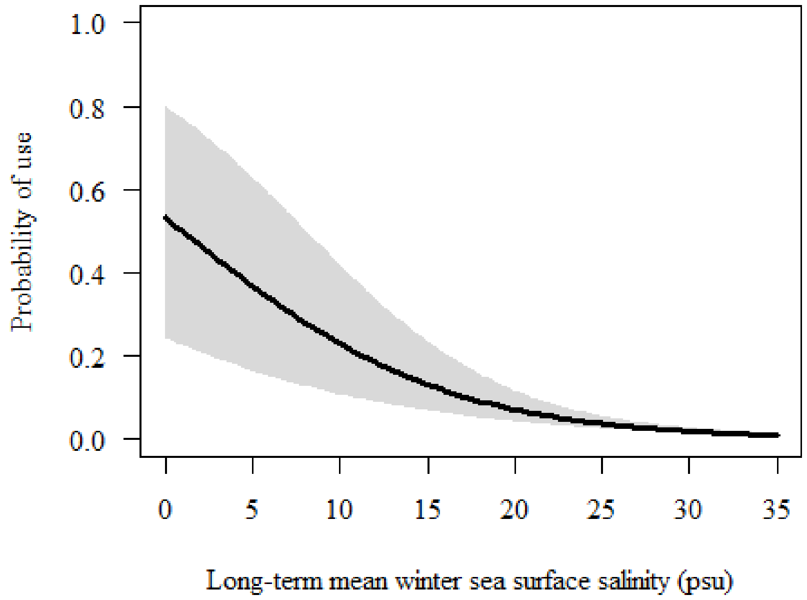


Figure 4-12. Generalized linear model results of the effect of long-term sea surface salinity (SSS6; PSU) on probability of second order resource selection of the adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range within the Mid-Atlantic Bight.

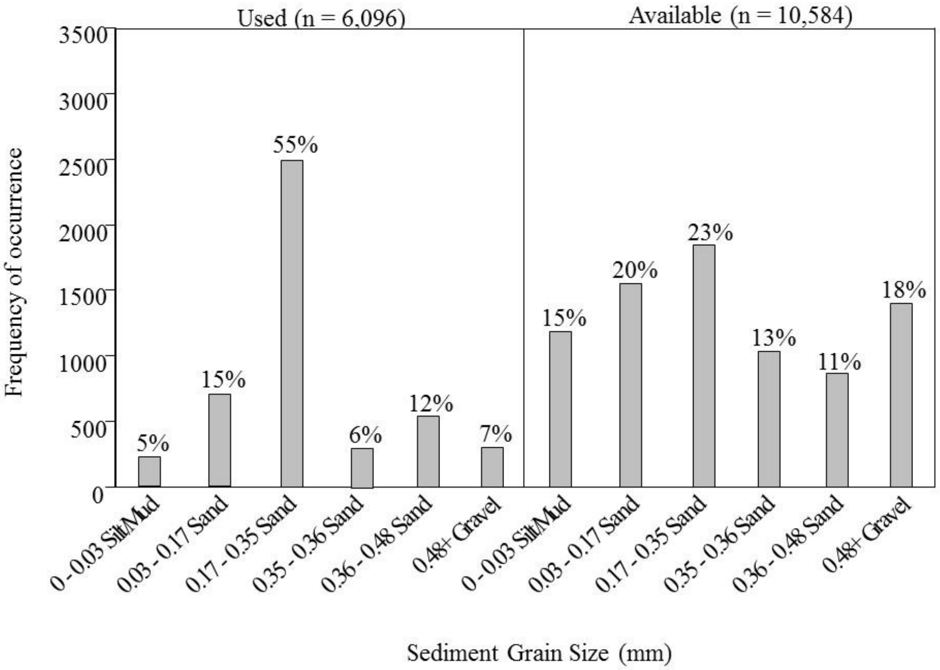


Figure 4-13. Frequency of occurrence among sediment grain sizes at used locations included in the generalized linear model predicting second order resource selection of the adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range versus randomly generated available locations within the Mid-Atlantic Bight.

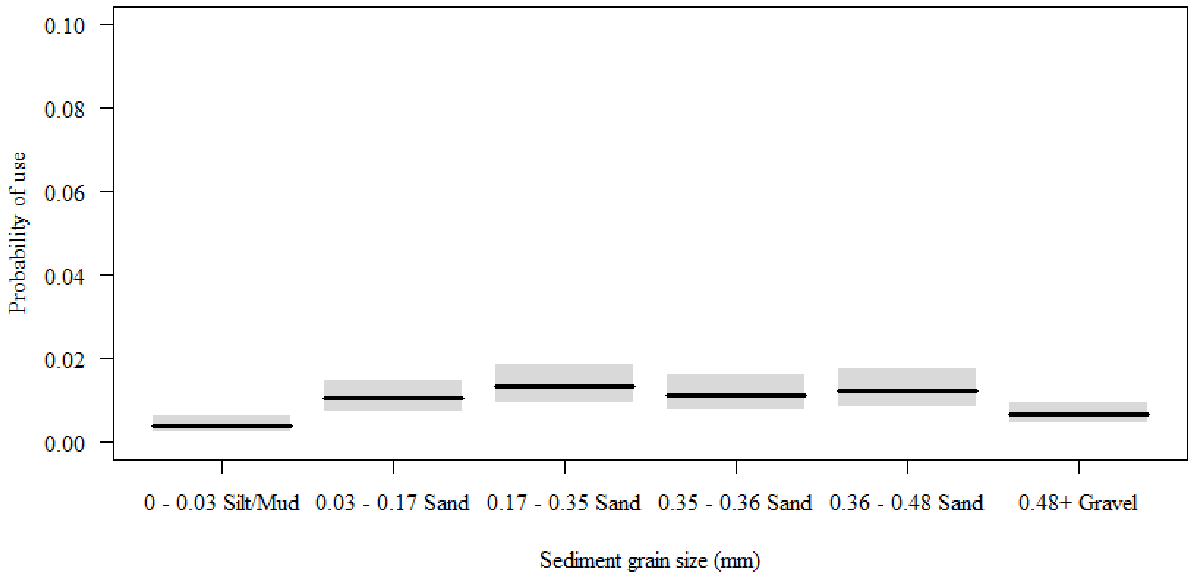


Figure 4-14. Generalized linear model results of the effect sediment grain size (mm) on probability of second order resource selection of the adult Surf Scoter (*n* = 62; 28 females, 34 males) winter home range selection in the Mid-Atlantic Bight.

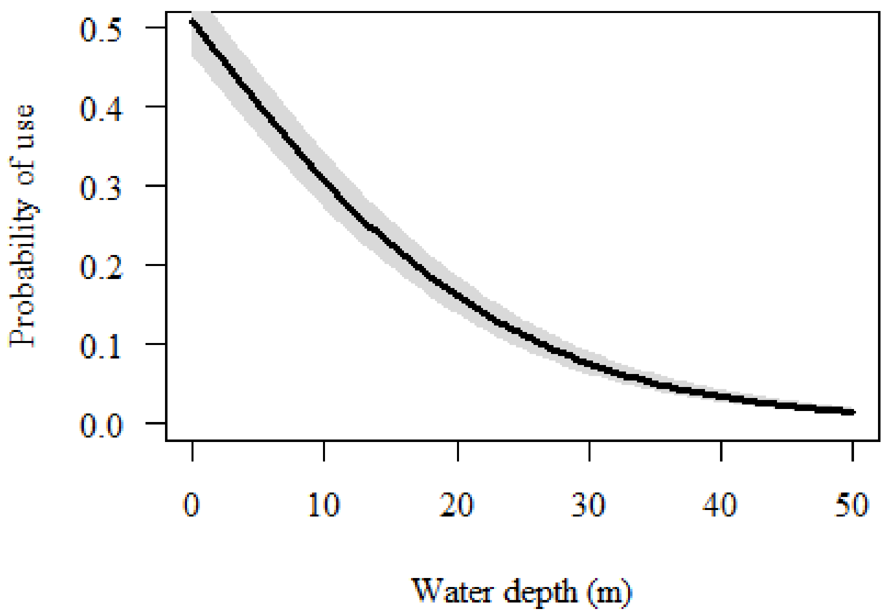


Figure 4-15. Generalized linear mixed model results of the effect of water depth (m) on probability of third order resource selection of adult Surf Scoter (*n* = 62; 28 females, 34 males) core uses areas within the Mid-Atlantic winter home range.

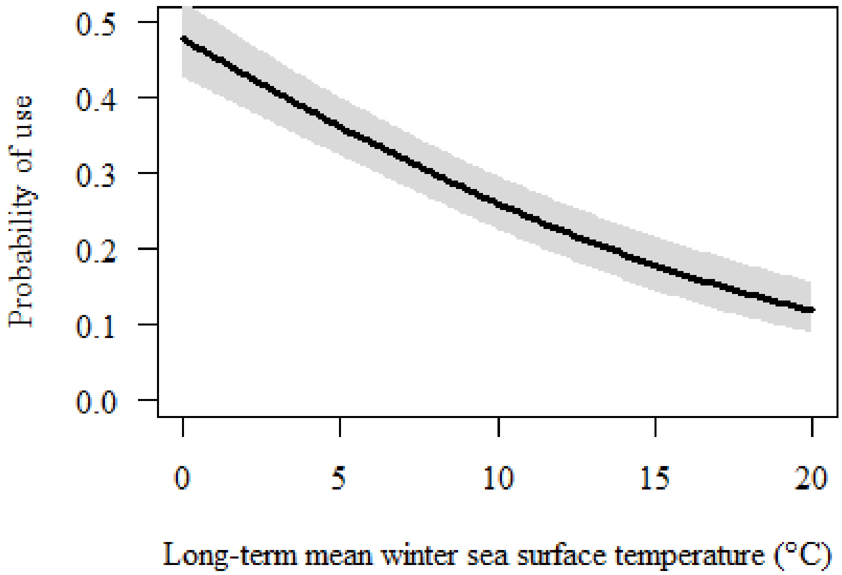


Figure 4-16. Generalized linear mixed model results of the effect of long-term sea surface temperature (SST10; ° C) on probability of third order resource selection of adult Surf Scoter (*n* = 76; 36 females, 40 males) core use areas within the Mid-Atlantic winter home range.

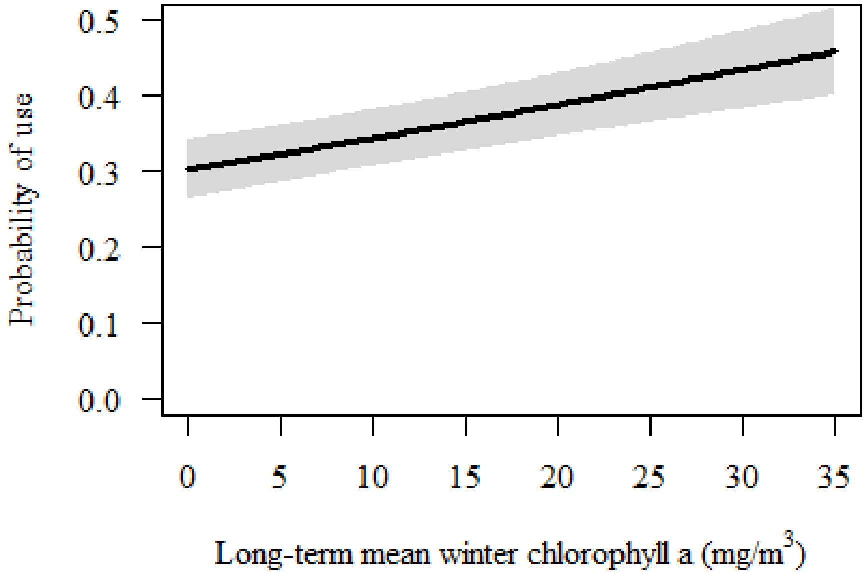


Figure 4-17. Generalized linear mixed model results of the effect of long-term chlorophyll *a* concentrations (CHLOR10; mg/m^3) on probability of third order resource selection of adult Surf Scoter (*n* = 76; 36 females, 40 males) core use areas within the Mid-Atlantic winter home range.

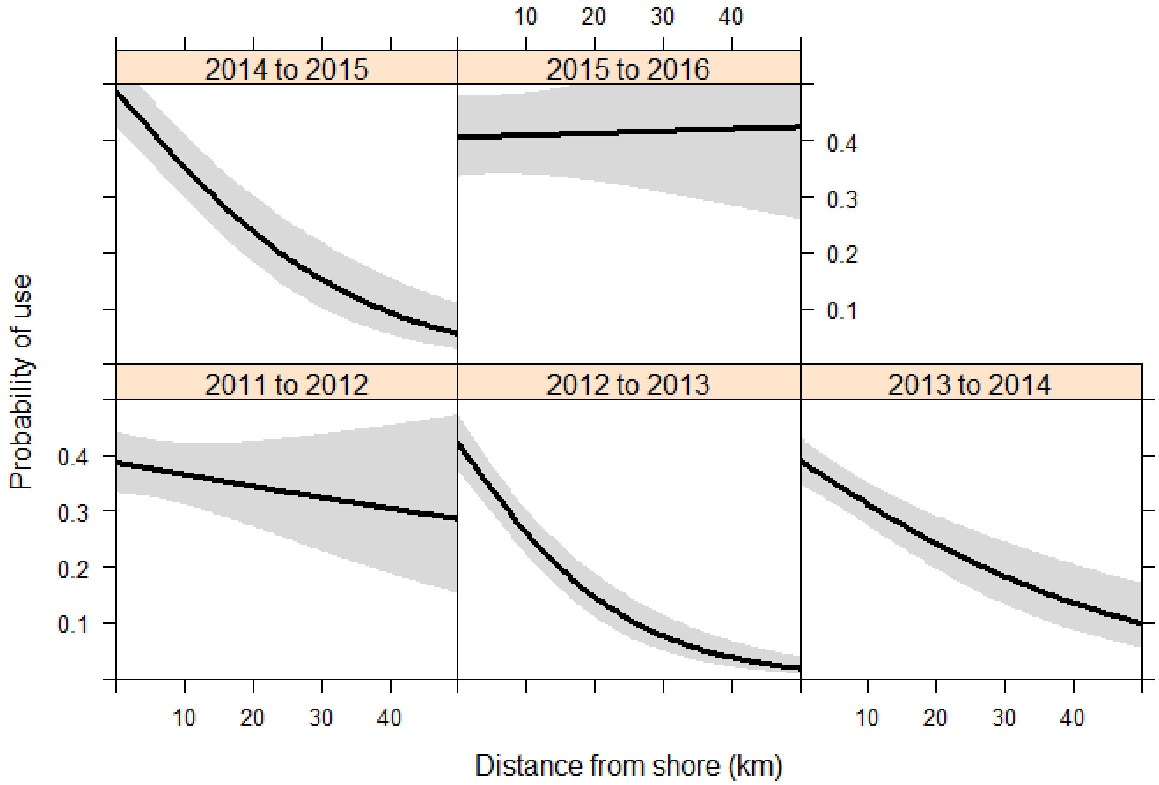


Figure 4-18. Generalized linear mixed model results of the effect of distance from shore on probability third order resource selection of adult Surf Scoter (*n* = 76; 36 females, 40 males) winter core use areas within the Mid-Atlantic winter home range for each winter sampling period.

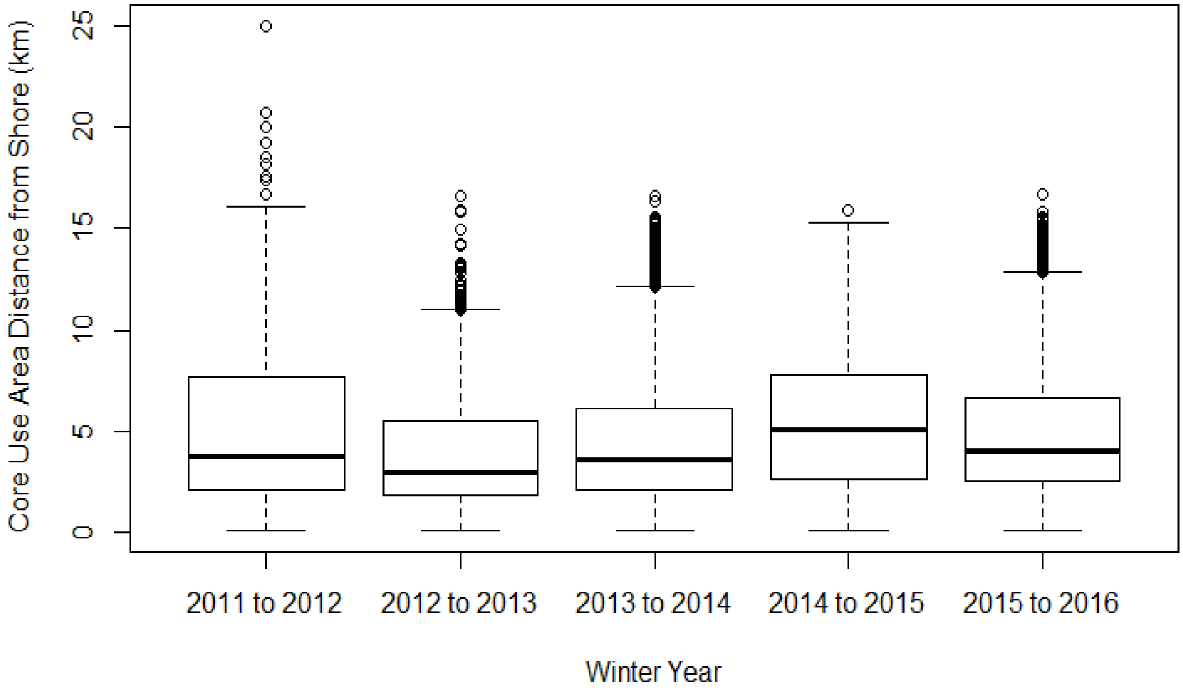


Figure 4-19. Differences in distance from shore (km) of adult Surf Scoter (*n* = 76; 36 females, 40 males) core use areas within the Mid-Atlantic winter home range among five winter sampling periods. Boxes represent median and interquartile range, whiskers represent 1.5 * interquartile range and hollow circles represent outlier values of distance from shore (km).

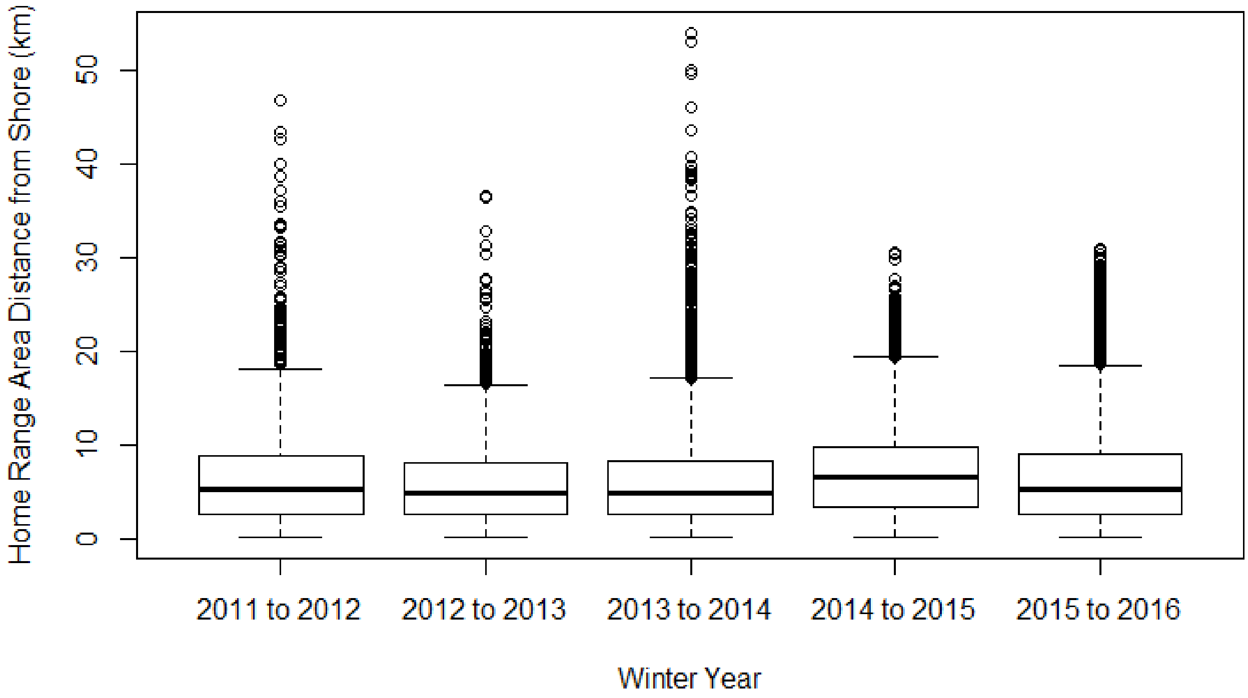
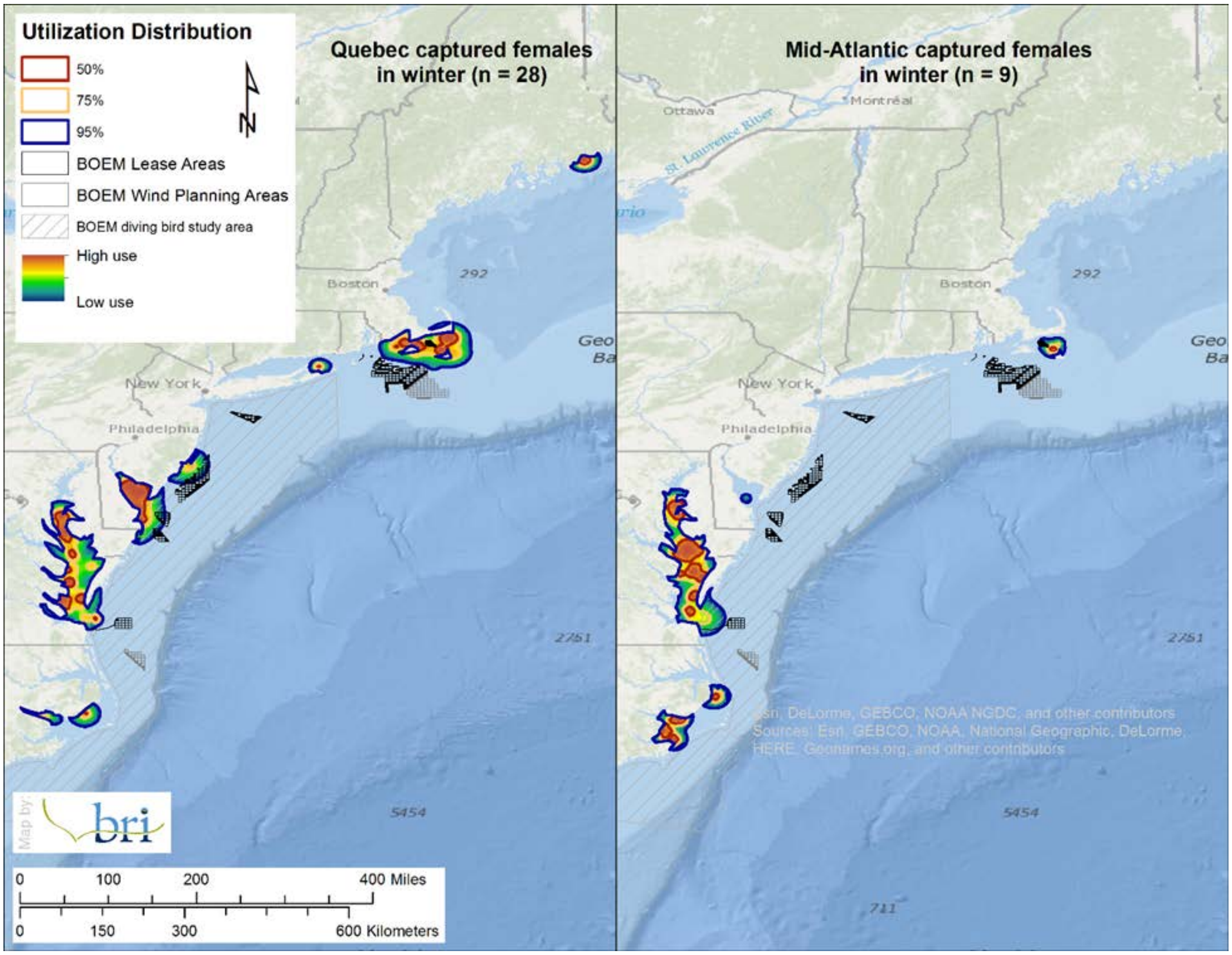


Figure 4-20. Differences in distance from shore (km) of adult Surf Scoter (*n* = 76; 36 females, 40 males) Mid-Atlantic winter home ranges among five winter sampling periods. Boxes represent median and interquartile range, whiskers represent 1.5 * interquartile range and hollow circles represent outlier values of distance from shore (km).



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 4-21. Location of wintering areas for Surf Scoters (all adult females) marked during fall staging on the St. Lawrence Estuary, Quebec, 2012 and 2013 (left; *n* = 28), and marked within mid-Atlantic coastal wintering study area (right; *n* = 9).

5. Captive Care and Surgery of Diving Birds Fitted With PTTs

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5.1 Summary and Objectives

This chapter reports on captive care and surgical implantation of Platform Terminal Transmitters (PTTs) in Northern Gannets (*Morus bassanus*), Red-throated Loons (*Gavia stellata*), and Surf Scoters (*Melanitta perspicillata*) during fieldwork conducted from 2012 to 2015. Captive care and surgery includes handling, sedation, transport, pre-surgical evaluation, anesthesia and analgesia, surgery, recovery, and release.

Our objectives for captive care and surgery were to:

1. Minimize stress and pain in implanted birds.
2. Minimize time birds spent in captivity.
3. Implant PTTs in such a way as to minimize impact on the activities and behavior of the birds after release.
4. Achieve optimal placement of the PTTs (e.g., antenna orientation) to maximize communication efficiency.
5. Collect biological specimens, measurements, attrition rates, and other data that could assist in our understanding of the health and needs of the implanted birds and determine how protocols can be improved to maximize positive outcomes.
6. Maintain safety of personnel in terms of zoonotic disease or physical harm.

5.2 Introduction

Implantation of intracoelomic PTTs is a common method to aid in tracking bird movements using satellites, in use since the early 1990s (Petersen and Douglas 1995). It involves the placement of a sealed satellite transmitter within the right abdominal cavity of birds with an antenna that exits dorsally near the tail. It is an inherently invasive technique that requires an experienced veterinarian to perform the surgery. External attachment techniques have been attempted on waterfowl previously but have met with limited success, particularly in diving birds, apparently because of the disruption of waterproofing properties of the feathers (Korschgen et al. 1996). External attachment on the back or tail of diving birds have the added burden of shifting the bird’s center of gravity changing energetics of flight and possibly disrupting the flow of water over the bird when diving (Vandenabeele et al. 2014) and of air over the bird when flying. The surgical procedure for implantation has not changed much from that described by Olsen et al. 1992 and Korschgen et al. 1996. The procedure is performed under general anesthesia with local and general analgesics, in a sterile environment, as required by animal welfare regulations. There are minor variations in surgical techniques by individual veterinarian or the particular circumstances of the project, such as drugs utilized, patient screening and preparation, where antenna cuffs are located, and how the antenna is passed through the body wall. Although analyses have been performed regarding surgical and post-deployment mortality within individual studies, very little published research exists that compares differences in survival between studies or variations in surgical and peri-operative care techniques (Iverson et al. 2006; D. Mulcahy and Esler 1999; D. M. Mulcahy and Esler 2010). Further variables that may also affect survival include physical attributes of the test subjects (e.g., age, sex, body mass, blood parameters, health status), locale where the birds are captured or released, and ambient weather conditions leading up to capture and immediately following release. Again, very little published research exists that correlates these variables with post-surgery survival, particularly with regard to weather (Sexson et al. 2014). The relatively large number of birds being processed for this project gave us a unique opportunity to collect equivalent data across species, veterinarians, and years of study so that a retrospective analysis could be performed to identify potential factors important to the immediate post-surgical survival of our sample.

5.3 Methods

5.3.1 PTT Preparation

PTTs were delivered by the manufacturer (Telonics, Inc., Mesa, AZ, USA; any use of trade, firm, or product name is for descriptive purposes only and does not imply endorsement by the U.S. Government) as smooth, plastic-coated units with a single protruding antenna. The antenna location and shape of the PTT body varied slightly during the course of the study, as depicted in Figure 5-1. We were responsible for attaching antenna cuffs, mesh, and antenna heat shrink-wrap, and for sterilizing the units prior to implantation. Project veterinarians Scott Ford and Glenn Olsen shared these duties throughout the project, usually producing the sterilized units separately and deploying them in their own surgeries or sharing prepared units as needed.

5.3.1.1 Antenna Cuffs

An antenna cuff consists of a synthetic felt material wrapped around a flexible silicon core (we used Kendall Quinton Felt Cuff, Tyco Healthcare Group LP). Their primary purpose is to prevent entry of pathogens into the body cavity along the antenna although they do serve a secondary role as points of attachment for the PTT and antenna. Similar cuffs are used for indwelling peritoneal catheters in human medicine. In use with PTTs, they are placed at or near the base of the antenna at the point where the antenna would exit the body wall. Locktite 410 glue (Henkel Corporation Engineering Adhesives) was used to cement the collars in place and the assembly allowed to set for 24 hours. For PTTs prepared by Dr. Glenn Olsen, an additional 1.5 cm piece of heat shrink tubing was placed above the cuff to further anchor it.

5.3.1.2 Nylon Mesh Bags

Birds undertake oscillatory movements during swimming and flight. To prevent movement of the PTT inside of the body cavity, the units are shrouded in knotless nylon mesh sacs to serve as anchoring points for sutures. These mesh sacs likely serve as substrates for scar tissue formation that further anchor them in place during the surgical healing process (G. Olsen, USGS, pers. comm.). Although multiple techniques exist for attachment of mesh to PTTs, all mesh in this study was applied by sewing it completely around the unit using nylon suture.

5.3.1.3 Sterilization

Gas sterilization using ethylene oxide (Anprolene, Andersen Sterilizers, Inc.) has become the normal and accepted method for sterilizing any surgical equipment which cannot be heat-sterilized, including intracoelomic PTTs (Mulcahy 2013). Transmitters are placed in a bag permeable to the gas but not permeable to bacteria. These bags are then placed in a special ethylene oxide sterilizing container in a well ventilated area, such as a fume hood, or into an automatic vented gas autoclave. The bagged transmitters are exposed to the ethylene oxide gas for 12 hours. This is followed by a 12-24 hour period when the bags and contents are allowed to “de-gas” before surgical implantation.

5.3.2 Capture and Restraint

Detailed capture, extraction, and restraint procedures are described in chapters two through four. The main method used was spot-lighting from a boat at night followed by capture with hand-net. In some cases, particularly for Surf Scoter capture, we used daytime floating mist-nets. We placed USGS Bird Banding Laboratory leg bands on all birds, usually just after capture, to aid in identification. In some cases, we collected blood and other biological samples in the field at the time of capture (e.g., for genetic sexing), but we collected these samples in most cases later at the surgical location.

5.3.3 Triage

All birds were briefly examined by field personnel immediately after capture to determine their fitness for implantation. Those that were not fit were released immediately. Criteria for fitness included:

1. Appropriate species, age, and sex.
2. Bright, alert, and responsive mental state. Normal reactions to approach and capture with symmetric, coordinated body movements.
3. No obvious fractures, missing feet, toes, or eyes, and no beak damage or other significant deficiencies not representative of healthy individuals in the population.

5.3.4 Sedation

Midazolam sedation has been found effective in a variety of bird species for facilitating examinations and other non-invasive diagnostic procedures (Mans et al. 2012; Valverde et al. 1990). In the first two years of our study, our intention was to sedate all birds immediately upon extraction from the net using midazolam hydrochloride 5 mg/ml (Hospira, Inc.) delivered intramuscularly. The dosage goal was 1-2 mg/kg. Because it was not practical to weigh each bird in the moving boats, doses were approximated based upon average weights from the literature or earlier years of the project. The approximated doses were preloaded and supplied to capture crew leaders prior to capture activity. Although some studies have explored intranasal use, one species in our study (Northern Gannet) did not possess external nares. For this reason and also to simplify and standardize delivery, we chose intramuscular injection for all species in the study. Because of potential for outliers in terms of body mass as well as potential for individually varied responses to midazolam, we directed crews to give a second half-dose if birds were still extremely fractious 15 minutes after the first dose. No crews reported using this second half-dose on birds. Administration times were recorded and relayed to the veterinarian when the bird was submitted for implantation.

5.3.5 Holding Crates and Transport

We placed captured birds into holding crates with net bottoms for transport back to land and then by vehicle to the surgery location. The net in these crates was knotless with maximum openings of 1.25cm. The netting was secured high enough in the bin so that the bird did not touch the bottom of the bin with any part of its body. Holes were provided for ventilation of the lower half of the bin, but not in the upper portion so as to avoid access with the bill and subsequent abrasions. In some cases, airline kennels were utilized but crews mainly used plastic storage bins (e.g., Rubbermaid Roughneck Storage Box). Large birds could sometimes knock off the lids so tape or shock cords were used to more securely fasten them down. During transport, we examined birds periodically to ensure that they were not distressed or too sedated. If overheating appeared to be a problem, as evidenced by open-mouth panting, we would wet down the feet of the birds with water.

Our goal throughout the project was to limit transportation and pre-surgical captivity to < 4 hours. This was not always possible if there were many birds to implant or if capture trips and ground transportation were prolonged. Because of the distances from shore for most capture operations, it was not practical to transport individual birds back to shore immediately after capture. Instead, birds were held in crates in the boat during capture operations for up to a few hours while further capture attempts were made. In almost all cases, ground transportation times were less than an hour to the surgery site although in one situation (Northern Gannets captured at Kiptopeke, VA and transported to Lewes, DE in March of 2014), transportation times were approximately 3 hours each way. We also transported several Red-throated Loons to a surgical site in Laurel, MD, several hours drive time from the capture location. At least one Surf Scoter was captured by Virginia DNR personnel and also transported several hours to a surgical location.

5.3.6 Pre-surgical Evaluation

A physical examination was conducted by the attending veterinarian to assess final fitness before anesthesia and surgery. Basic elements of the evaluation included:

1. Body weight (recorded in grams) within expected range for species, cohort, and time of year.
2. Evaluation of pectoral muscle mass, thigh mass, sharpness of the pubic bones, and coverage of the ribs (*note:* muscle condition and adipose stores were difficult to assess externally in water birds).
3. Cloacal temperature between 37.8°C (100°F) and 41.7°C (107°F).
4. No major feather damage, wounds, fractures, or other serious injuries.
5. Normal mentation, responses, and coordination.
6. Eyes: Normal pupillary light reflex and menace responses.
7. Packed Cell Volume (PCV) ≥ 38% (as determined by centrifugation, where available; *note:* PCV was used inconsistently as a pre-surgical evaluation tool, mainly due to the delays that it presented to processing prior to surgery.)
8. Pink, moist oral and cloacal mucus membranes.
9. Normal respiration and heart sounds on auscultation, normal rhythms, warm feet and extremities.
10. Normal droppings present, expelled normally.

5.3.7 Analgesia, Anesthesia, and Patient Monitoring

Significant discomfort is likely for any invasive surgical procedure, so selection of appropriate analgesics to manage pain in wild birds was an important consideration. In psittacines, butorphanol has been shown to produce good analgesia (Paul-Murphy, Brunson, and Miletic 1999). It may be beneficial to provide opiate analgesics, such as butorphanol, prior to surgery and during the immediate post-operative period. (Paul-Murphy, Brunson, and Miletic 1999). There are anecdotal concerns by some implant surgeons that opiates may negatively alter mentation and predator avoidance in ducks post-release. No studies have been done to demonstrate the duration of effects in sea ducks although in other studied avian species the half-life has generally been around 4 hours (Sladky et al. 2006; Paul-Murphy 2007). However an opposing argument can be made that severe discomfort will also alter a bird's behavior prompting it to preen more and dive and feed less. In light of this, we decided to use butorphanol pre-operatively in this study at a dose of 1 mg/kg intramuscularly at least 10 minutes prior to induction of anesthesia.

We used Isoflurane gas anesthesia delivered in oxygen via a non-rebreathing circuit throughout the study. Induction was accomplished with 5% isoflurane in approximately 700 ml/kg/min pure oxygen flow delivered by a mask that fit over the beak and nares. Once immobilized, we intubated with a silicone non-cuffed endotracheal. The neck and head were kept extended at all times after intubation until removal. We secured the endotracheal tube to the lower bill and/or head using paper medical tape or adhesive tape. After intubation, we maintained isoflurane at a level that produced a surgical plane of anesthesia. Generally this was about 2-3% during the most painful portions (PTT placement) of surgery, and the gas concentration was gradually reduced thereafter while suture placement and closure was being performed. We provided intraoperative positive pressure ventilation as 1-2 gentle sighs per minute while the bird was spontaneously ventilating. If spontaneous ventilation discontinued, we administered 4-6 breaths per minute or as directed by the veterinarian.

We administered line blocks of lidocaine or bupivacaine (or combinations thereof) not totaling more than 2 mg/kg, along the abdominal ventral midline during surgical preparation. With rare exception, we did not utilize post-operative analgesia.

We monitored our patients with electronically amplified esophageal stethoscope and in-line ventilation monitor. If available, we used other modalities such as a Doppler pulse or pulse-oximeter. We monitored core temperature using an esophageal probe or thermometer inserted into the cloaca. We recorded vital signs at major events in the surgical process, generally every 3-5 minutes. Parameters recorded included core temperature at induction and termination of anesthesia (sometimes intraoperatively), heart rate, ventilation rate, and anesthesia setting. The major events used for these readings were induction, initial skin incision, preparation of the PTT pocket, trocarization, PTT insertion completed, antenna collar sutured, PTT anchored, body wall closure completed, skin closure completed, anesthesia discontinued, and bird recovered (e.g., placed into its recovery enclosure).

5.3.8 Surgical Preparation

There are no published studies of surgical site preparation ("prep") solutions and their effects on feather waterproofing. However, staff at the Patuxent Wildlife Research Center (G. Olsen and M. Perry, USGS, pers. comms.) has confirmed that a variety of substances can cause serious detriment to waterproofing for several days post-application in healthy captive sea ducks. Such substances include adhesives from tape, water-soluble lubricant jelly, isopropyl alcohol, chlorhexidine solution, and povidone-iodine. In PWRC's research, alcohol and chlorhexidine surgical scrub solutions (both common substances used for surgical preparation) were found to have some of the longest-lasting adverse effects on feather waterproofing.

Once anesthetized, we laid the bird on its back on a pad of closed cell foam (for insulation from the table) and towel. The head and neck were extended off of the pad so that they were below the level of the heart. Patient monitors were put in place. We prepared the ventral midline of the abdomen from the interpubic region to a distance of approximately 4-6 cm. anteriorly. We performed an initial wipe down of the feathers with water-soaked gauze sponges, followed by a prep solution to facilitate spreading of the feathers. Prep solutions varied by surgical team. Dr. Ford's team utilized individual sterile packets of water-soluble jelly (Surgilube, Savage Laboratories – contains a very small amount of chlorhexidine gluconate as a bacteriostatic agent). Dr. Olsen utilized a polyvinyl alcohol/glycerin/propylene glycol product marketed for human use (Freeman/pH Beauty Labs, Inc.). In both cases, the purpose was to part the feathers and expose the skin without requiring the removal of feathers, which would more severely disrupt thermoregulation. We applied these products to maximize exposure to the skin without plucking. In most cases, we applied Micropore tape surrounding the site to keep feathers retracted and to decrease adhesive residue and feather loss from the overlying sterile transparent surgical drapes. Finally, we placed a sterile transparent drape (Avian Surgical Drapes, Jorgensen Laboratories) over the surgery site and bird.

5.3.9 Surgical Procedure

We incised the skin on the abdominal ventral midline starting near the interpubic space and extending 3-4 cm anteriorly. Next we incised the linea alba. We assessed the subcutaneous and intracoelomic adipose tissues and subjectively scored on a scale of 1 (none) to 5 (abundant) with 3 being approximately average. We used blunt dissection to create a pocket in the right side of the body cavity, lateral to the viscera, leaving air sacs as intact as possible.

From inside the body cavity, we identified the caudal vertebral column and caudal aspect of the ischium. The exit site for the antenna was immediately adjacent to these structures, depending upon the species. In species that had more free space beyond the caudal edge of the ischium, placement was shifted farther caudal to the edge of the ischium (see Table 5-1 for guidelines for specific species and PTT configurations). We placed an absorbable suture in the inner body wall just lateral to the anticipated antenna site and left it untied. Dr. Ford utilized braided absorbable suture on a taper needle (3-0 Vicryl, Ethicon) whereas Dr. Olsen utilized monofilament absorbable suture (3-0 or 4-0 PDS II [polydioxanone], Ethicon). Dr. Olsen previously designed a trocar and sleeve combination used to create a passage for the antenna from inside the coelomic cavity to the outside, exiting to the right of the tail. The trocar is a section of 2.4 mm stainless steel intramedullary pin approximately 10 cm in length, blunt at one end and sharp at the opposite end. The cannula or sleeve passes over the pin and is about 9 cm long, made from 3.2 mm diameter aluminum tubing. Leaving at least 5 mm clearance from the ureter (and vas deferens in males), we pressed the trocar/sleeve through the body wall and out through the skin in a slightly medial direction. An assistant would verify emergence of both the cannula and trocar and assist by pulling the trocar through leaving just the cannula in place. We opened the PTT package and removed the deactivation magnet. We verified the number of the unit and entered the number on the patient's procedure form and when a receiver was available, function of the unit was verified. The suture that was placed earlier was then passed through the PTT's antenna collar and the antenna inserted into the sterile end of the cannula. After an assistant verified passage of the antenna, they pulled the cannula out and applied gentle traction to the antenna to assist the surgeon in inserting the rest of the PTT. Once the PTT was in place, the antenna was oriented anteriorly along the spine and slightly to the bird's left. The antenna collar suture was closed thereby securing the collar to the inside of the body wall in a simple interrupted stitch. Once in place a visual inspection was performed to ensure no debris had been drawn inside with the PTT and that no intestinal entrapment existed.

We placed a simple interrupted suture in the craniolateral body wall and the mesh of the cranioventral aspect of the mesh of the PTT. This suture was intended to prevent the PTT from pivoting excessively on the collar suture during the oscillations of flight and could also be used to pull the ventral surface of the PTT laterally (which in turn directed the antenna straight up dorsally or slightly to the left). Often, where space and time permitted, particularly in loons and gannets, we placed a second suture at the caudal end of the ventral aspect of the PTT to provide additional stability. One last inspection was made for debris and visceral entrapment and then we closed the body wall and skin in separate simple continuous patterns. Subcutaneous tissues, if abundant, were sometimes closed with a simple continuous pattern.

We then rolled the bird to ventral recumbency, and we checked the position of the antenna and the status of the antenna exit site. If we found excessive slack around the antenna exit site, then we had the option to apply a last external stitch through the skin and body wall into the antenna collar.

Feather samples, morphometrics, and other samples, if not collected earlier, were then collected under light anesthesia.

All field procedures, including surgical implantation of tags, were reviewed and approved under Institutional Animal Care and Use Committee number 2010-10 (USGS-PWRC).

5.3.10 Recovery and Convalescence

We recorded a post-operative cloacal or esophageal temperature, and recovered birds in an upright position with the head up and the body wrapped in a towel for warmth. We extubated birds when coughing was elicited or the eyes were open. We removed any excess mucus from the oropharynx. Blood or thick mucus on the tube, though uncommon, was recorded when present. We gave birds a sterile crystalloid fluid such as Normosol-R or lactated Ringer's solution, at 35-50 ml/kg, warmed, and delivered subcutaneously. The feathers of the abdomen were gently cleaned using water (no detergents) to remove as much blood and surgical prep agent as possible. They were returned to their transport crates and kept in a warm, quiet, darkened environment until release. Dr. Olsen's team also provided gavage feeding at 15-20 ml/kg body weight using Emeraid Piscivore (Lafeber) after full recovery from the anesthetics, sometimes just before release.

5.3.11 Release

We released birds from shore near where they were captured. In some cases, we took birds by boat back to capture areas for release. Our release criteria for this study included:

1. Weather conditions at the release site that will minimize energy expenditure (no strong sustained winds or heavy precipitation, average to above-average ambient temperature).

2. Bird holds head up, responds to visual or auditory stimuli, avoiding capture and struggles when restrained. Clear breathing, clear eyes and nares, normal color to mucus membranes, normal body temperature, and feet are warm to the touch.
3. No blood or fluid oozing from surgical sites. No subcutaneous emphysema (palpable as a crackling sensation under the feathers).
4. Normal droppings in crate, expelled with normal effort.
5. Feathers dry and groomed over incision site.

5.3.12 Biological Sampling

We collected blood, feathers, and other samples and measurements as time and bird condition allowed. This sampling is largely covered in chapters two through four. Samples were collected at various times including initial examination, just after anesthetic induction, during post-surgical anesthesia, or during the recovery phase. Blood samples never exceeded 1% of body weight and were generally much lower than this. In 2014 and 2015, additional blood samples were at times taken for hematology and basic serum biochemistries. We collected heparin blood samples (usually 3-5 ml) and saved them for mercury analysis by Biodiversity Research Institute. Additional blood was collected on Nubuto strips for later use for DNA analysis and sex determination in monomorphic species (Northern Gannet and Red-throated Loon). One sample in heparin and one in a plain tube were used for complete blood counts (CBC) and serum chemistry analysis. In the last year of the study (2015), iSTat instantaneous basic blood panel analysis was also done on fresh blood samples based on earlier work that used this technique as a way to predict post-release survival (Sexson et al. 2014).

5.3.13 Post-Release Monitoring and Fate Determination

In addition to telemetry locations collected for each species (see chapters 2 - 4), PTTs provided data that could be interpreted to determine activity levels, internal (body) temperature, and tag voltage. Based on these data, determinations were made that birds were either alive, dead, or had malfunctioning transmitters.

5.3.14 Pre-Release Mortalities

Birds that died during surgery or required euthanasia underwent post-mortem examination to determine cause and were disposed of in accordance with local regulations or returned to USGS Patuxent Wildlife Research Center and incinerated after all testing was completed.

5.3.15 Statistical Analyses

We used a Cox proportional-hazards regression (PHREG) model (Therneau and Grambsch 2013; Cox 1972) to examine the influence of atmospheric, demographic, and surgery covariates on bird mortality within 60 days of PTT deployment using Proc Phreg procedure Breslow method within the program SAS (SAS/STAT 14.2 User's Guide 2016)**.** The programming statement method (Powell et al. 2012) was used to incorporate time dependent covariates. Individuals that survived beyond 60 days or were lost due to transmitter failure, were considered right-censored, which in survival analysis framework is similar to an individual being removed from the study before the event occurs (SAS/STAT 14.2 User's Guide 2016). Prior studies of seaducks have suggested 14 days as the window for attributing mortality to tagging surgery (Mulcahy and Esler 1999, Sexson et al. 2014, SDJV 2015). However, due to sample size limitations that would have resulted from using the 15 day mortality window for proportional-hazards regression modeling, we expanded our estimate of ‘fully recovered’ to 60 days (as in Olsen et al. 1992) to evaluate the potential influence of different covariates on survival.

In our study, most mortalities likely resulting from implantation occurred within 30 days of implantation, thus we only included birds that transmitted >30 days after release in analyses to further reduce bias from birds that could have been negatively affected by transmitter implantation and handling

Our time dependent covariates were surface sea temperature, distance from shore, full daily air temperature (2 m above the surface), surface categorical rain (true/false for any precipitation), surface total precipitation, east-west wind speed, total cloud cover, atmospheric pressure, surface roughness of water bodies (as measured using the Charnock parameter), north-south wind speed, and precipitation rate. Using the most accurate location per duty cycle for each species, atmospheric covariates were paired using Movebank for 14 days after deployment when we thought the weather would have the most impact after surgery. Time independent covariates tested represented morphometric information (age, sex, mass) and surgery information (time elapsed for various components of processing as outlined above, surgeon experience, distance between capture and deployment, use of midazolam, presence of captivity-related injuries, total days of deployment ending when birds died or transmitters stopped functioning) for each bird. To identify the top model for each species, we ran a stepwise selection procedure based on the Akaike Information Criterion (AIC; SAS/STAT 14.2 User’s Guide 2016). Significance was determined at the 5% level.

5.4 Results

Between 2012 and 2015, we implanted a total of 227 satellite transmitters in diving birds, 86 in Red-throated Loons, 78 in Surf Scoters, and 63 in Northern Gannets. The following subsections provide results from variably-sized subsets of these data, resulting in differing sample sizes. The reason for this is that records were eliminated if they did not provide specific data for the particular variables being presented. For instance, if medical records did not specifically mention midazolam or include a provision for mentioning midazolam use (positive or negative), then they were excluded.

5.4.1 Overall Post-Release Outcomes

Tables 5-2 and 5-3 summarize the numbers of birds and their survival and tag fate statistics. Twenty-two implanted birds were removed from this independent variable analysis due to missing or inadequate data (leaving 205 individuals in the sample). Overall mortality rate during the first two weeks post-release was 19.5%, with Red-throated Loons experiencing the highest rate (25%) and Northern Gannets experiencing the lowest rate (6%). Subjects were tracked for a mean of 226 (SD=160) days post-deployment. Gannets experienced the longest known survival and transmitter functionality (mean of 280 days with a maximum of 570 days).

5.4.2 Body Mass

We recorded body mass from all 227 of the birds deployed with transmitters. A summary is presented in Table 5-4. Body mass varied substantially within each species group (30% variation for Red-throated Loon, 20% for Northern Gannet, and 19% for Surf Scoter). Mass did not significantly influence the survival of any of our focal species ($p > 0.05$).

5.4.3 Time Held in Captivity

We documented elapsed times that subjects were transported, under anesthesia, in surgery, and in recovery, as well as the total time birds were held from capture to release. Results are presented in Table 5-5. In some cases recovery times also encompassed transport times back to a position near the capture site (see section 5.4.6 below). We did not calculate times for each species separately because times were similar and methods did not vary substantially between species. According to our analysis, length of time in captivity was not related to survival within the first 60 days after surgery.

5.4.4 Sedation

We used midazolam sedation either at the point of capture or as a pre-anesthetic for surgery. Seventy of 208 (31.6%) implanted birds included in our analysis received midazolam. Mean survival for individuals of all species receiving midazolam was 234 days and for birds not receiving midazolam, survival was 242 days (Table 5-6). Use of midazolam was not significant in the top model explaining mortality during the first 60 days post release (see 5.4.8 below).

5.4.5 Surgeon Experience

We compared survival time in days for birds (all three species combined) implanted by experienced vs. less experienced surgeons. We defined experienced surgeons as those who had performed 50 or more similar PTT implant surgeries on living birds. Our model found no significant variation in survival based on surgeon experience (Table 5-7; see section 5.4.8 below).

5.4.6 Release Location Relative to Capture Location

We looked at the distance between the release and capture sites for each release where this information was available (n = 159; Table 5-8). Distance was measured as the shortest curvilinear distance between capture and release point. This information was utilized in our multivariate analysis. We found that the distance between release and capture sites was not significant in our top model explaining mortality during the first 60 days post release.

5.4.7 Capture Trauma

We looked at the impact of capture- and transport-related injuries on post-release survival (Table 5-9). There were 20 out of 200 birds that demonstrated injuries, most of them considered minor. Despite the implementation of several measures to minimize capture stress during field work, there was a higher propensity for Red-throated Loons to present to the veterinarian with injuries, as compared to other species, suggesting particular sensitivity to capture stress and injury in the species. Our multivariate analysis found a positive correlation between post-release mortality and injuries in Red-throated Loons (see 5.4.8 below). Injuries had significant effects on loon survival beyond 60 days after surgery (P = 0.0392). The hazard of death within the first 60 days after surgery decreased 53.2% if the individual did not have capture- or transport-related injuries.

5.4.8 Modeling Results of Capture, Surgery, and Release

Table 5-10 summarizes our findings for Red-throated Loon. North-south wind speed and additional medical problems (e.g., capture or transport trauma) found on initial examination were the sole significant variables ($P = 0.0124$ and $P = 0.0392$, respectively) related to 60-day survival post-capture and handling for Red-throated Loon. Red-throated Loons were 14.2% more likely to die within 60 days of deployment if there was greater north wind speed within 14 days of release, and 53.2% more likely to die if they had capture- or transport-related injuries prior to release.

Table 5-11 summarizes our findings for Northern Gannet where total time under anesthesia was the only significant (P=0.0027) variables affecting 60-day survival post-deployment. Northern Gannets were 8.6% more likely to die within 60 days of deployment with increased anesthetic times.

None of the covariates significantly determined the survival of Surf Scoters 60 days after implantation and release ($p > 0.05$).

5.5 Discussion

This chapter describes the veterinary medical procedures used to implant satellite transmitters (PTTs) in Red-throated Loons, Surf Scoters, and Northern Gannets. An enormous array of variables may have influenced survival of tagged birds, including those under our control (e.g., technique selection, patient selection, location, time of year) and those not under our control (e.g., weather, intrinsic patient factors such as life experience and immune competence). In order to carry out a study of this size, multiple teams were needed, which introduced subtle and gross variations in techniques and experience. Furthermore this study’s primary objective was to study bird movement, so it was not designed with equal sample sizes or controls from the aspect of medical data. Despite this, our results illuminate several potential factors that may influence post-deployment survival in these species that are useful for future studies to consider.

As mentioned earlier, the surgical procedure we utilized was similar to that in use by most veterinarians over the past 25 years. There have been improvements made to suture materials and the sedatives and analgesics available. Suture material made with polydiaxaone, poliglecaprone, or other derivatives is both fully absorbable and has a higher tensile strength than materials utilized in earlier studies.

We present in Table 5-1 important landmarks for the placement of the trocar/sleeve combination to create the antenna exit port. We recommend veterinarians planning to do this surgical procedure for the first time on a new species to obtain a carcass or two of the species to use to locate the internal landmarks and the angle of the antenna exit port to ensure proper, near vertical, placement of the antenna.

Table 5-2 presents overall fate of subjects in this study. We had a PTT failure rate of 2.4% (5/207). Table 5-2 demonstrates that most post-release mortality (85% or 40/47 of all known deaths in the first 28 days) occurred in the first two weeks after release. This is consistent with observations of the authors in their other implant projects (Hamilton et al.1988, Olsen et al. 1992). Both Red-throated Loon and Northern Gannet are considerably larger birds than the Surf Scoter (Table 5-4). The transmitters weighed about 40 g and, thus, were a much smaller percent of body weight for these two species. This may have given them an advantage in terms of long-term survival, as reflected by longer average survival of these two species (Table 5-3). However, Red-throated Loon experienced the highest acute mortality (Table 5-2). Our multivariate analysis did not reveal any significant contribution of body mass for any of our focal species. Although it’s tempting to draw conclusions about relative mass of PTTs and implant subjects, it would appear from our results that there are more variables to consider. For instance, these species all utilize very different means of foraging and exploit different feeding depths and habitats. The extra weight or discomfort from surgery will likely affect foraging efficiency to a varying degree with each species.

While mass was not a significant factor on survival, body mass is a crude measure of health, particularly with species whose body weight fluctuates seasonally and regionally, and may have not adequately measured individual condition. Future studies should clarify pre-surgical health assessment parameters that may best predict health status and, hence, short-term post-release survival. This could include specific blood tests or even rejection of individuals that demonstrate poor adipose reserves upon initial stages of surgery.

We tabulated times for travel, anesthesia, surgery, recovery, and total time in captivity in Table 5-5. The greatest variation in duration of processing segments occurred for recovery time, measured as the time between conclusion of surgery and release. This is because recovery included both true anesthetic recovery time and the time required to transport the bird from the surgery location to the release location. In some cases the surgery location was hours from the point of capture. When release was from a boat, the release sometimes did not occur until the following evening when the boat again went out for more capture attempts. Also, the post-operative holding time was sometimes lengthened by adverse weather conditions. Recovery time varied from 31 to 2082 minutes (0.52 to 34.7 hours) yet there was no significant correlation between recovery time and survival after release in our stepwise analyses. We found it noteworthy that distance from capture to release point also was not significant ($P < 0.05$) for any of the three species in our analysis. Thus, releasing the bird on shore near the surgery location versus taking the bird out to the capture location on the sea appeared to have no effect on post-release survival. However, all release locations were relatively close to capture locations, usually within 10 km or less, distances the birds could readily fly.

In this research study, midazolam was given to some birds, especially Red-throated Loons, at the time of capture to relieve stress and avoid injuries associated with caging. We found that use of midazolam had no effect on the 60-day post-release survival of any of the species in our modeling of factors contributing to mortality (Tables 5-10 and 5-11).

In some cases when midazolam was used at 1 mg/kg at the time of capture, Northern Gannets were found to be recumbent and somnolent eight or more hours later. It should be noted that the antagonist agent, flumazenil, was never utilized in any subjects in this study. Perhaps it may have provided rapid recovery as is seen in other avian species. However, given the unusually slow recovery of gannets from the effects of midazolam, caution in its use with this species and perhaps other members of the order Suliformes is recommended.

In our analysis of medical data independent from modelling, all three species showed at least minor increases in post-release longevity where midazolam was given pre-surgically. This is particularly clear with Surf Scoter where the mean survival increased from 225 to 340 days. However, sample sizes were widely disparate (54 and 7, respectively) and modelling demonstrated no significant ($P < 0.05$) contribution to survival. These results are similar to results from a small study of scoters implanted in the Gulf of St. Lawrence (Tim Bowman, pers. comm.). In that study, midazolam or same-volume saline injections were administered to birds at capture, and personnel were blinded to which was being utilized. Although no significant improvement in survival was noted for Red-throated Loon in our analysis, we observed individuals given midazolam to be calmer for transport and appeared to have less cage-related injuries, though we did not quantify these observations of demeanor sufficiently for a statistical assessment. However, one of two factors found independently significant (Table 5-10) in our stepwise modeling for Red-throated Loon was a medical flag, which usually indicated an acute contusion to the bill, carpi, or feet occurring between capture and surgery. The use of midazolam would calm Red-throated Loon and hopefully reduce such injuries. While midazolam use did not appear to significantly affect loon survival in our regression modeling, this may have been because there was inconsistent use, thus limiting numbers of records to compare.

In Table 5-7, we examined the role that surgeon experience had on post-release survival. Experience was categorized into two groups by those that had conducted > 50 PTT implant procedures (“Experienced”) or ≤ 50 (“Other”). For this analysis, all three species were combined. Even though mean survival was slightly longer with a more experienced surgeon, no significant ($P < 0.05$) effect related to surgeon experience was found when modeling the 60-day post-release survival of the 3 species (Tables 5-10 and 5-11). Even surgeons who had not done the procedure before were supervised by a more experience surgeon, and this would contribute to the lack of significant difference seen for post release survival for surgery performed by experienced versus less experienced surgeons.

In examining birds before surgery, the veterinarians often discovered injuries related to capture and transport, and older injuries from past experiences. Older injuries that may further compromise the bird post release, such as loss of sight in one eye, were factors for rejecting the bird for implant surgery. There were a small number of birds that suffered more serious capture-related injuries such as open dislocations of toes or, in one case, a luxation of the stifle (Dr. Ford’s records indicate 3/144, Dr. Olsen’s data unavailable). These birds were not implanted and therefore not included in this analysis since survival times would not be known. Table 5-9 considers abrasions, damaged feathers, contusions and other soft tissue injuries that were recent and that we related to capture and handling. We found this type of injury in 11% of birds (22/207). These wounds were cleaned and medicated at the time of surgery. Even though these were considered minor wounds, they were a factor in 60-day post-release survival modeling for Red-throated Loon (Table 5-10), but not for Surf Scoter and Northern Gannet. This is the first time, to our knowledge, that capture-related injuries have been negatively correlated with survival post release. We recommend extra vigilance with transport crate design for Red-throated Loon, paying particular attention to holes or seams where they may abrade their beaks. Over the course of the study, field crews made modifications to transport methods to help loons reduce self-inflicted injury. Sedative use should also be considered as well as other measures, such as placing the birds in a quiet part of vessels or vehicles, to keep the birds calm. As mentioned above, midazolam was used with only a subset of loons.

Weather has often been informally discussed as an important factor in determining the post-release survival of captured and implanted water birds. While surgery likely has at least a temporary negative effect on ability to forage, thermoregulate, and move about, it is logical to assume that inclement weather may also exacerbate all three of these same challenges to survival. To explore the impact of weather on survival, we used individual relocation data from the implanted transmitters to look at local weather conditions for each bird during their first 14 days post-release. We incorporated this information in our stepwise modeling. For Red-throated Loon, north-south wind speed was determined to be a significant factor in survival. Stronger north-south winds may have been indicative of colder and poorer winter weather conditions, affecting the ability of loons to forage, thermoregulate, and/or move about.

In our study, weather covariates were related to survival in only one of three species, Red-throated Loon. This could have indicated that the effect of weather conditions on survival of implanted birds varied among species, or could have been related to an inability of our sample to adequately detect such effects for some study species. Weather as a variable affecting wildlife handling and release has not been well studied. While Hamilton et al. (1988) found that adverse weather conditions had a negative effect on released diurnal raptors, few other studies have looked at weather as a variable when releasing birds. We believe that future studies should conduct similar weather factor analyses as part of their post-study reviews, particularly where losses are potentially high.

It could be argued that modeling the impact of weather is a dubious exercise since we cannot easily conform capture activities to weather predictions. We believe that the answer lies less in pre-emptively predicting and avoiding the effects of weather and more in understanding and possibly accounting for the impact of weather in post-study survival analyses. If we can understand what specific weather elements most affects post-deployment survival for a given species, location, or time of year, then we can better understand whether outcomes (successful or not) are likely due to weather or other controlled variables (e.g., new techniques). As we make changes to capture, handling, and medical protocols, we will be able to more precisely identify the impact of those changes. In short, knowing critical variables, including those out of our control, helps us better understand the needs of the birds and better determine the impacts (after filtering out the impacts of weather) of our procedures as we alter them. It is logical to assume that this is probably more so the case on wintering grounds where foraging, movement, and rest are more difficult. Finally, having a better understanding of the interactions among capture, handling, surgery, and environmental stressors could improve our interpretation and analysis of movement data.

Anesthesia duration had a significant impact on survival of Northern Gannet. This species generally recovered very quickly from anesthesia where midazolam was not used and anesthetic duration and surgical protocols did not differ significantly from the other species. A deeper analysis of vital signs collected during surgery may help elucidate whether there is a specific critical support need for this species. Some examples could be monitoring exhaled CO_2 in combination with assisted ventilation or monitoring blood pressure in combination with IV fluid support. Surgeon experience had an impact on surgery times since newer surgeons often required twice or more the amount of time as an experienced surgeon (mean = 26.9 minutes for experienced surgeons with SD = 5.7, 47.3 for less experienced with SD = 17.4). The effect was less severe on anesthetic times since there’s a given amount of preparation regardless of surgeon (mean = 51.7 minutes for experienced surgeons with SD = 11.1 and 74.1 for less experienced surgeons with SD = 22.6). However, surgeon experience did not directly have an impact on survival in any of the species in our study. While it seems prudent to always limit anesthetic times as much as possible in any species, it seems particularly true of gannets.

There are several other medical factors that could be monitored in the future. A few examples include improved pre-operative health assessment tools to identify the fittest individuals, surgical preparation techniques that afford the least impact to waterproofing, determining the best sedatives and analgesics and their proper doses, and identifying the most critical components of anesthetic monitoring and support for each species group. Ideally, these would be explored first in a controlled, captive research environment. Conducting medical research in the field introduces more complexity to processing, slowing down operations and creating more logistical difficulties. Also, it introduces variables with unknown consequences to the survival of the subjects, possibly detracting from the primary goal of monitoring movements of “normal” birds. Finally, there’s no way to monitor untagged control birds for comparison making meaningful interpretation of the data very difficult if not impossible. Even the tagged birds themselves provide very limited medical data after release. For all these reasons, we urge that future work support captive medical studies of species groups that they deem important for future telemetry studies.

5.6 Conclusion

In conclusion, in the course of this study, 227 birds were implanted and deployed with satellite transmitters. Overall acute mortality (occurring during the first 15 days post-deployment, the period considered most critically impacted by medical procedures) was 19.5%. Red-throated loons demonstrated the highest rate of acute mortality at 31.3%. Our multivariate analysis suggests that injury during capture and transport was the most critical medical factor affecting survival in loons. For gannets, anesthetic duration was most critical. No medical factors were statistically significant related to survival in scoters. North-south wind velocity was the only non-medical factor to have a significant adverse relationship with survival, affecting only Red-throated Loons. No non-medical factors were significantly related to survival in gannets or scoters. To build upon our efforts, we have provided a list of medical components that we recommend veterinarians in future implant studies track (Table 5-12).

Table 5-1: PTT Configuration details including internal landmarks for antenna passage by species.

Species	**PTT Config.[1]**	**Internal Landmarks for Antenna Passage**	**Other Notes**
Red-throated Loon (*Gavia stellata*)	1B	Caudal border of ischium, between right ureter and caudolateral corner of ischium	The ureter is very close to the collar site in this species due to narrowness of pelvic canal. The trocar should be directed slightly dorsomedially during passage. This should pass between m. caudofemoralis and m. caudae. No dissection data for *G. stellata* although use in live birds has been successful. Dissections performed in *G. immer*.
Surf Scoter (*Melanitta perspicillata*)	1A/B	Caudal to the caudal border of the ischium as close to the caudal vertebrae as possible and about 5-10 mm ventral along the caudal abdominal wall from the ischium.	The surgeon should aim for the dorsal third of the caudal body wall between the pelvis and pubic bones. You want to be as close to the tail as possible without impinging the ureter with the antenna collar. This position is particularly important if using PTTs of the 1B design (Figure 5-1).
Northern Gannet (*Morus bassanus*)	1B	Intra-ischial notch of the caudal border of the ischium (not the caudoischial notch or the ischiopubic notch)	Trocar directed vertically tight against the medial ischiadic notch. The femorocaudalis muscle should be drawn ventrally to avoid perforation. This can be accomplished with a thumb inside the body cavity, surgical drape pressed down around the right side of the rump with fingers strumming against the skin of the bird—the muscle is readily palpable.

[1] See Figure 5-1 for configuration details

Table 5-2. Fate by Species for Red-throated Loons (RTLO), Surf Scoters (SUSC) and Northern Gannets (NOGA) implanted with satellite transmitters during the winter and spring of 2012-2015 in coastal waters from North Carolina to New Jersey. Includes only PTT-tagged birds whose ultimate fate was predictable from telemetry data (e.g., still alive, died, or radio failure), and does not include birds that died or were euthanized prior to deployment or that were missing dates of last transmission in tracking data sets provided by project biologists.

	ALL	**RTLO**	**NOGA**	**SUSC**
PTT Failure 0-60 days	5 (2.4%)	0 (0%)	4 (6.6%)	1 (1.6%)
Mortality 0-14 days	40 (19.8%)	20 (25%)	6 (9.8%)	14 (21.9%)
Mortality 15-28 days	7 (3.4%)	5 (6.3%)	0 (0%)	2 (3.1%)
Mortality 29-60 days	9 (4.5%)	6 (7.5%)	2 (3.3%)	1 (1.6%)
Survival >60 days	141 (69.8%)	49 (61.3%)	49 (80.3%)	46 (71.9%)
Totals	**202 (100%)**	**80 (100%)**	**61 (100%)**	**64 (100%)**

Table 5-3: Number of days post-release that PTTs transmitted locations for implanted Red-throated Loons (RTLO), Northern Gannets (NOGA), and Surf Scoters (SUSC) along the US mid-Atlantic Coast (North Carolina to Long Island, NY) during winter and spring 2012-2015. Data includes only birds whose date of last transmission was available and whose transmitters did not experience technical failure within the first 60 days. It should be noted that most tags ultimately stopped transmitting due to battery (or other technical) failure rather than mortality. End dates were not available at the time of analysis for 23 individuals.

	ALL	**RTLO**	**NOGA**	**SUSC**
n:	197	80	56	61
Mean	226	216	280	190
SD	160	176	141	142
Max	570	544	570	418

Table 5-4: Body Mass (g) for Red-throated Loons (RTLO), Surf Scoters (SUSC), and Northern Gannets (NOGA) captured along the US East Coast, North Carolina to New Jersey, winter and spring 2012-2015. Data from all birds tagged with PTTs.

	ALL	**RTLO**	**NOGA**	**SUSC**
n:	227	86	63	78
Mean	2019	1869	3389	1075
SD	956	285	350	102
Min	900	1400	2600	900
Max	4200	3050	4200	1310

Table 5-5: Travel, anesthesia, surgery, and recovery procedure times (in minutes) for Red-throated Loon, Surf Scoter, and Northern Gannet combined. All birds were captured and implanted along the US East Coast, North Carolina to New Jersey, winter and spring 2011-2014. Data from all birds tagged with PTTs.

	Travel (min)	Anesthesia (min)	Surgery (min)	Recovery (min)	Total (min)
n	137	227	227	227	227
mean	134	54	29	311	691
SD	75	14	10	304	502
min	10	25	14	31	317
max	610	118	83	2082	3780

Table 5-6: Correlation of survival (days) to use of midazolam sedation at capture for Red-throated Loons (RTLO), Surf Scoters (SUSC), and Northern Gannets (NOGA) captured along the US East Coast, North Carolina to New Jersey, winter and spring, 2012-2015. Several medical records did not specify whether or not midazolam was utilized. This accounts for the lower sample size of individuals than were tagged.

	ALL		**RTLO**		**SUSC**		**NOGA**	
Midazolam Use	Yes	No	Yes	No	Yes	No	Yes	No
%	37%	63%	84%	16%	11%	89%	22%	78%
n	70	138	51	10	7	54	12	43
Mean Survival (d)	234	242	226	188	340	225	209	207
SD (d)	197	221	170	169	385	269	150	153

Table 5-7: Average survival (in days) Relative to Surgeon Experience. Surgeons were grouped by relative experience. Surgeons that had performed more than 50 PTT implant procedures were considered experienced. Does not include PTT failure within 28 days of deployment or birds for whom no tracking end date was available.

	Survival (days) by Surgeon Experience	
	Experienced	**Other**
n	185	21
mean	221	202
SD	161	170

Table 5-8: “Release distance” as measured in kilometers (km) from capture location to release location. Limited to birds for which capture and release coordinates were recorded. Distance is the shortest curvilinear distance between capture and release points.

	Distance (km)
n	**159**
Mean	**13**
SD	**14**
Min	**2**
Max	**101**

Table 5-9: Relationship between average survival (in days) to capture or transport injury for Red-throated Loons (RTLO), Surf Scoters (SUSC), and Northern Gannets (NOGA) captured along the US East Coast, North Carolina to New Jersey, winter and spring, 2012-2015. Assessed during pre-operative examination noting presence or absence of abrasions and contusions. Excludes PTT radio failures within 28 days of deployment or those for whom no tracking end date was available.

	ALL		**RTLO**		**SUSC**		**NOGA**	
Capture/Transport Injury	Yes	No	Yes	No	Yes	No	Yes	No
n	20	180	11	69	5	58	4	53
%	10	90	14	86	13	87	7	93
Survival Mean (days)	284	233	196	219	449	214	321	273
SD (days)	405	176	158	180	811	192	273	148

Table 5-10: Surgery and weather data modeled using PHREG Procedure, stepwise selection for alpha of 0.05 for Red-throated Loons.

Step	Effect entered	Effect removed	df	Number In	Score Chi-Square	Wald Chi-Square	Pr>ChiSq
1	NSWS		1	1	5.8742		0.0154
2	Flag		1	2	4.1395		0.0419

NSWS = north-south wind speed in m/s
Flag = Flagged for medical problems (mostly bill, carpal, or foot abrasions sustained in capture or transport) at time of pre-surgical examination
n = 77 birds

Table 5-11: Surgery and weather data modeled using PHREG Procedure, stepwise selection for alpha of 0.05 for Northern Gannets.

Step	Effect entered	Effect removed	df	Number In	Score Chi-Square	Wald Chi-Square	Pr>ChiSq
1	AX		1	1	19.5097		<0.0001
2	Cloud		1	2	5.0199		0.0251
3		Cloud	1	1		1.6398	0.2004

AX = total anesthetic time in minutes
Cloud = cloud cover 0-1
n = 58 birds

Table 5-12: List of medical data recommended for collection during future studies. This list is provided to encourage consistency of data collection among veterinarians conducting satellite transmitter implants.

- Dates and Times for capture, arrival at the surgery location, examination, anesthetic induction, surgery start (first incision), surgery end (closure of skin), anesthetic end, recovery (released into holding bin or kennel), and release. 24-hour time and inclusion of date is recommended for clarity since much of this work spans the midnight hours.

- GPS coordinates of capture, surgical facility, and release.

- Body weight while dry, before surgery.

- Body temperature and specification of whether it is collected per cloaca or esophageal. This should be collected at the very least at the start and end of anesthesia.

- A simple Boolean variable (e.g., true/false) for designating the presence of captivity-related injuries. This was termed a “medical flag” in our study. More detailed descriptions should occur in medical notes but this was helpful in identifying the frequency of injuries without use of a scoring system subject to individual interpretation.

- Boolean variables for use of midazolam, parenteral fluids, or other drugs. Again, details of dosing should be recorded in medical records but a simple true/false variable makes it easy to perform comparisons between surgeons or studies.

- A subjective assessment of adipose reserves as seen during surgery. This is highly open to interpretation but until a more precise tool can be developed, it may at least provide a basis for some comparison of health.

- Other peri-operative diagnostics such as PCV, white blood cell counts, serum chemistry panels, or serum lactate. Also averages of heart rate, ventilation rate, end-tidal CO^2, or blood pressure. Ideally these would be averaged only during a surgical plane of anesthesia.

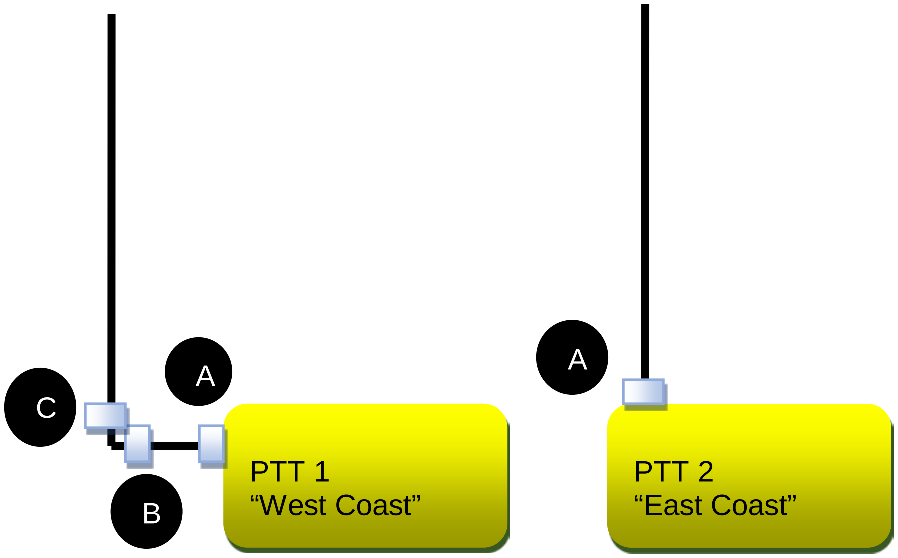

Figure 5-1: Basic configurations of PTTs implanted in marine birds during the study: dorsal-exiting antenna (right) and those with caudal-exiting antenna (left). There were also variations in antenna shape and antenna collar position (A = against the unit, B = just proximal to the first antenna bend, C = just distal to the first antenna bend). Specific configurations were not tracked with enough detail to perform a detailed analysis of their contribution to surgical difficulty or patient survival.

6. Testing New Attachment Techniques and Technologies to Assess Fine-scale Movement Patterns of Marine Birds

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6.1 Summary

Several types of experimental attachment techniques were tested on each study species, Surf Scoters (*Melanitta perspicillata*), Red-throated Loon (*Gavia stellata*), and Northern Gannet (*Morus bassanus*), including traditional Teflon-ribbon style harnesses, sutures, and harnesses made of silicone moulding. Silicone harnesses, which were deployed in 2014 and 2015, offered the best balance between high retention rate and low behavioral impact of any of the techniques, as they allowed for natural changes in a bird's body weight during migration. However, the impact of these harnesses was highly variable among species as Red-throated Loon and Surf Scoter experienced high rates of confirmed mortality during this first year of field deployment. This was likely due to intolerance of the harnesses, buoyancy issues at dive depth, harness breakage during normal preening behavior, hydrodynamic drag while pursuing prey, or a combination of all of these factors. In 2016, a second iteration of the harness design deployed on three Surf Scoters, had better success, with two birds successfully arriving in Nova Scotia during migration. Although mortality was still confirmed for one individual, these harnesses improved tag longevity compared to 2014 deployments, and provided novel data on foraging ecology, movement behavior characteristics (i.e. speed, overland movements, stopovers, altitude) and activity during this critical migration period. A complete loss rate of transmitters deployed on Northern Gannets in 2014 was attributed to the silicone material being too fragile and breaking during preening. Because of this, we opted for a refined tail-tape procedure to tag birds in 2015. A 3D printed tail-tape adapter was highly effective for tagging Northern Gannet during migration, allowing secure mounting of the transmitter at the base of the three central tail feathers. Retention of these tags was limited to < 5 months due to natural tail feather molt. We conclude that the use of silicone harnesses to attach external transmitters to marine birds shows promise, but remains inadvisable to deploy on diving birds without further refinement of the design and research to better understand and mitigate associated impacts on the birds they are attached to.

6.2 Introduction

An important consideration for biologists tracking wildlife is what residual impacts transmitters and tagging activities (capture, handling) have on the bird post-release (Barron 2010). If a tag's presence on a bird results in lasting behavioral differences compared to untagged individuals, the value of the resulting data is greatly diminished, so we took great care in selecting the best method and technology that would minimize impact on the focal species of this study. Implanted transmitters, used with the majority of birds in this study, is a proven technology and procedure, and has been the technology of choice to effectively track aquatic bird species that dive for prey. For diving species, implantable tags have been reported to result in less impact to post-release survival and behavior (Korschgen et al. 1996, Hupp et al. 2003, Iverson et al. 2006, Latty et al 2010) than external tags attached using harnesses (Barron 2010, Dzus and Clark 1996, Robert et al. 2006, Pietz et al. 1993). However, this perceived impact may be strongly associated with the species or the staff performing the surgical procedures (see Chapter 5). For example, Iverson et al. (2006) found that implanted transmitters were retained and provided minimal signal loss in Surf Scoter. However, for some species, mortality rates associated with surgically implanted transmitters can be higher than external attachment procedures. Anesthesia, surgery, and other post-release factors (e.g., predation, hypothermia, stress) can contribute to mortality (Olsen et al. 1992, Iverson et al. 2006, Sexson et al. 2014). In addition, some studies have reported behavioral and reproductive effects associated with implants (e.g. Hatch et al. 2000, M. Perry, USGS, pers. comm.). Latty et al. (2010) recorded longer diving and foraging times in Common Eiders (*Somateria mollissima*) implanted with platform terminal transmitters (PTTs). Kenow et al. (2003), who implanted dorsal transmitters in Common Loons (*Gavia immer*), reported abnormal behavior and fledgling neglect.

External back-mounted harness-style attachments have also been used to attach transmitters to many waterbird species, avoiding complications associated with implant surgeries. However, harnesses-attached transmitters can also have negative effects on behavior, reproduction, migration, and survival (Perry 1981, Pietz et al. 1993, Dzus and Clark 1996, Robert et al. 2006, Lamb et al. 2017). Diving birds appear particularly prone to these effects. For example, Vandenabeele et al. (2014) reported adverse effects on the flying behavior of Northern Gannets. Decreased feeding time and increased preening and wing-flapping have been seen in both Barrow's Goldeneye (*Bucephala islandica*; Robert et al. 2006) and Canvasbacks (*Aythya valisineria*; Perry 1981) immediately after harnessing and release. The duration and severity of impacts of harness-based tag attachment on behavior is variable among species. While Lamb et al. (2017) observed excessive preening immediately after harnessing, behavioral effects diminished after several days and did not appear to result in mortality post-release. In contrast, Robert et al. (2006) reported 100% loss of harnessed birds, compared to 44% for color-banded birds only. This makes it difficult to predict whether atypical behaviors are a result of harness materials, harness fit, or presence of the transmitter (or some combination of all the above).

Researchers have recently begun testing new materials to construct harnesses, such as soft, flexible silicone. These flexible materials are used to create a one-piece harness that can be slipped over the wings and bodies of birds (Vandenabeele 2013). Flexible harnesses allow a tagged bird's body mass to fluctuate without compromising fit, compared to traditional materials. Although not used on diving ducks, early results on dabbling ducks were positive with no apparent impact on behavior (Vandenabeele 2013). Biologists have also experimented with different external transmitter attachment methods including gluing and suturing and use of subcutaneous anchors (Wheeler 1991, Iverson et al. 2006). However, sutures and subcutaneous anchors provide very limited tag retention durations (<100 days; Wheeler 1991, Iverson et al. 2006), making the attachment techniques unsatisfactory for studies which aim to better understand patterns across the annual cycle, such as migratory connectivity and annual site fidelity (i.e., tag retention of ≥ 1 year sought). In light of data limitations provided by sutures and subcutaneous anchors, and deleterious effects from harnesses or backpack transmitter attachments on seaducks and other diving birds, surgically implanted PTTs may be the best currently available technique for obtaining long-duration tracking data on these species.

In addition to the concerns about implanted PTTs listed above, some limitations exist in the frequency and accuracy of location data provided by implanted PTTs. Implanted PTTs are internal and therefore are not capable of solar recharging, which is common in modern external PTTs. Thus, there are trade-offs between transmitter "duty cycle", the amount of time a tag transmits location data to an Argos satellite, and battery life. More frequent locations provide a more continuous record of a tagged individual's movement, but come at the cost of tag longevity (Meyburg and Fuller 2007). For example, studies that aim to delineate migration routes would require more continuous location data transmission, which uses up PTT battery power, causing it to be depleted over a shorter period. Conversely, obtaining locations across an entire annual cycle precludes the collection of frequent location data due to battery limitations, and may lead to location gaps that make it harder to discern precise movement pathways. In addition to battery limitations, PTTs may produce location accuracy errors due to limitations in how their transmissions are detected by satellites (i.e. the Doppler effect; Meyburg and Fuller 2007). Some researchers have reported that the highest accuracy PTT locations (i.e., $\bar{x}$ = 200 m for best locations received) only occur 10 to 15% of the time (Meyburg and Fuller 2007).

New technologies have resulted in longer lasting and more accurate remote tracking devices for large-bodied birds. Solar-powered technology is currently used in many transmitters, allowing more frequent transmissions and longer battery life. Solar-powered transmitters produced by a number of wildlife tracking companies have lifetimes in excess of five years versus two to three years for transmitters without solar capability. Some newer satellite transmitters also incorporate global positioning system (GPS) receivers and data loggers (Meyburg and Fuller 2007). Solar-powered GPS-satellite transmitters can be programmed to record exceptionally accurate GPS locations (within 18 m) at much more frequent intervals than standard PTTs, as batteries are recharged regularly by the built-in photovoltaic panels. Unlike standard PTTs, this can permit nearly-continuous tracking coverage of an individual. Emerging cellular tracking technology using the Global System for Mobile communication (GSM) gives researchers the option to bypass the Argos satellite system altogether. With GPS-GSM tags, GPS positions and associated data such as travel speed, direction, temperature, and altitude (though altitude data are of limited utility due to low precision) are gathered by the data logger and transmitted to cell towers, rather than through the Argos system. Transmitters out of cellular network range can store over 100,000 GPS locations in the data logger before they must be transferred via cellular signal, allowing more data to be logged compared to satellite-based systems, data to be transferred faster using less energy, and data retrieval to occur with less expense to the researcher.

In order to increase total tracking durations above levels currently attainable with implantable PTTs, and to reduce the invasiveness and potential mortality associated with implants, we tested several attachment techniques on our study species in captivity. We also tested GPS-GSM technology to determine whether solar-powered cellular transmitters fitted with GPS receivers could provide more accurate and complete data on migration routes, stopover sites, feeding and behavioral modeling in order to examine the influence of weather and time of day on offshore movement events. A prerequisite for applying this new technology on seabirds for this project was the development of a suitable way to attach the units externally that minimized handling time while also ensuring the device remains attached for the life of the unit with as little effect to flying, diving and other behaviors as possible.

6.3 Methods

6.3.1 Captive Experiments to Test Harnesses and Transmitters

All captive work took place at the USGS/PWRC's Seabird Research Facility. Birds were maintained in 11.5 m^2 pens with gravel substrate and a conical rubber-lined pool (2.1 m diameter and 70-80 m deep at the center) with constantly flowing fresh water. All behavioral dive trials were completed in two large cement tanks (1.83 x 1.83 x 2.44 m) with three windows specifically built for studying underwater behavior at the facility. All study animals were maintained on Mazuri® Seaduck Diet *ad libidum.* All animal research was approved by USGS/PWRC's Animal Care and Use Committee.

6.3.1.1 Transmitter Placement and Selection

GPS-GSM transmitters from two manufacturers, Microwave Telemetry, Inc. and Cellular Tracking Technologies (CTT), were tested for performance and effects on diving birds. Microwave Telemetry, Inc. provided both live and non-functional replica "dummy" solar-powered GPS-GSM 25-g transmitters with external antennae, and CTT provided live and dummy solar-powered GPS-GSM 34-g transmitters with internal antennae (Figure 6-1). The transmitters used in the captive study collected hourly GPS data uploaded daily via the GSM connection. Using active tags (rather than just 'dummy' transmitters) during this captive work allowed for testing of transmitter performance and under varying types of weather conditions (e.g. icing, cloud cover, storms, etc.).

6.3.1.2 Attachment Techniques

In 2013-2015, we tested three different methods of attaching solar-powered GPS transmitters on Surf Scoters: sutures (n = 3), Teflon harnesses (n = 5) and silicone harnesses (n = 16). Weights, hematology and serum chemistry analysis, behavioral time budgets and dive performance were recorded and compared across the three treatments.

6.3.1.2.1 Suture Attachment

In summer 2013, dummy transmitters were attached to two Surf Scoters using stainless steel sutures to determine if the suturing material and method was appropriate to test on the species. In 2014, 3 additional adult Surf Scoters were tagged with Unify® polyester surgical sutures size 3/0 to further investigate the method with a different material. Sugru, a self-setting rubber, was used to form 5-mm high ridges that ran length-wise down the bottom of the transmitter, to form rails that raised the profile of the solar-powered transmitter above the feathers. These served to raise the transmitter off the backbone of the bird, as well as minimize contact with feathers. Raising the transmitter also helped reduce feather coverage of the solar panel, as birds often preen feathers over the PTT (Davenport et al. 2012). Birds were anesthetized under a 5% isoflourane and oxygen mix, and monitored at 3% during the procedure. Size 3/0 stainless steel sutures were looped through the transmitter's attachment points and down under the skin, through the dorsal protrusion from a vertebral process, and out of the skin. Sutures were tied off and a quick setting epoxy was used to attach the knot and tag ends securely to the transmitter. After recovering from anesthesia, x-rays were taken to help determine proper fitting. Birds were then returned to their pens, and monitored daily for 60 days.

6.3.1.2.2 Teflon Harness Attachment

Five Surf Scoters received Teflon tape harnesses in 2014, attached using a two-loop harness design (Dywer 1972). Transmitters had three anchor positions, one on the front on the transmitter, and two at the rear on each side. Next, the transmitter was placed on the back of a scoter, while the front loop was run around the chest of the bird and connected on the front anchor point in the same manner and the others. The loop was tightened to the point where two fingers could still be easily inserted between the bottom of the transmitter and the bird's body (Cumming et al. 2011). Finally, this was repeated for the rear loop on the transmitter. Once outfitted and researchers were satisfied with harness fit, the birds were released back into their holding pens and monitored for 60 days.

6.3.1.2.3 Suture Attachment

We developed a soft, flexible silicone harnesses for Surf Scoters, Red-throated Loons, and Northern Gannets based largely on a design by Vandenabeele (2013). We used Alumilite High Strength II silicone mold making rubber to fashion a one-piece harness. This rubber is extremely soft and flexible, with high tensile and tear strengths. After prototyping a mold and adjusting the size to reflect measurements taken of captive Surf Scoters and Red-throated Loon and Northern Gannet carcasses, a 3-D printed mold was created for pouring the harnesses (Figure 6-2). During the pouring process, lengths of braided brass were used to create loops at each terminal end, and at the top of the loop. These loops were then connected to the transmitter to create a one piece package that could be slipped directly into position on the bird.

Transmitters had three points of attachment per harness: one placed posteriorly on each side of the transmitter, and one on the anterior end. Square brass loops soldered to the housing served as attachment sites on the transmitter, connecting harnesses to transmitters with brass rings that were crimped closed. The rings were attached to the harnesses with loops at the ends of braided brass wire molded inside the silicone harness (Figure 6-3).

Owing to its high tensile strength and UV and abrasion resistance, a multifilament fishing line was used to bond the silicone harness to the transmitter. After testing and refining different attachment techniques, we attached silicone harnesses to four Surf Scoters in the colony to determine durability of the silicone harness material, and observed bird behavior and harness performance during molt when the birds were at their lowest weight. Birds were monitored for 60 days. Body weights, feather wear, and behavioral observations were measured for all birds before and after harnesses were attached to determine proper harness fit.

A single captive Red-throated Loon held at PWRC was used to test silicone harness designs as with scoters. For added reference points, larger Common Loon carcasses were used to assess fit for heavier individuals. Similarly, we used Northern Gannet carcasses to fit and test various iterations of silicone harness designs at PWRC, as no captive populations of these birds were available. We also worked directly with Sylvie Vandenabeele, who provided expertise and further measurements from wild birds used in her dissertation (Vandenabeele 2013).

In 2014 and 2015, additional refinements were made to the silicone composition and manufacturing techniques to lower weight, increase tensile strength, and improve harness durability. We moved to using a 6.3 mm rounder router bit (Figure 6-4) to machine a custom harness mold from high-density foam material. An additional 12 Surf Scoters were behaviorally evaluated while wearing these improved silicon harnesses. This, in combination with a 3-D printed model of a gannet (Figure 6-4), allowed for more rapid assessment of fit prior to the 2015 field deployments.

All captive procedures used with study animals, including the testing of different attachment methods, were reviewed and approved under Institutional Animal Care and Use Committee number 2012-07 (USGS-PWRC).

6.3.1.3 Body Weight

Two baseline body weights were taken prior to outfitting birds with transmitters: seven days before and immediately before attachment. Following attachment, birds were weighed twice a week for eight weeks. Surf Scoters are sexually dimorphic, so weight data were normalized by analyzing percent change in weight. Repeated measures ANOVAs were used to determine if significant changes occurred within tagging method ‘treatments’. Post-hoc Tukey’s HSD mean comparison tests were then applied to determine if differences existed between treatments (SAS 9.3). All tests were considered significant at $P < 0.05$.

6.3.1.4 Behavioral Observations

Twelve Surf Scoters were separated into two pens, with three males and three females in each pen. Three birds in each pen were randomly assigned to be instrumented with a CTT transmitter using a silicone harness, with the remaining birds acting as controls. Surf Scoters were observed in each pen for one hour, four days each week for seven weeks. Behaviors (feeding, resting, locomotion, maintenance, courtship, alert) were recorded following Portugal et al. (2010) with a continuous scan-sampling methodology. Each bird was weighed once each week every week until data collection was completed. Behaviors were compiled into four primary categories (preening, resting, on and off water) and analyzed with Tukey’s HSD mean comparison test to compare the means of each category and determine treatment differences (PRISM GraphPad).

6.3.1.5 Dive Performance

Prior to collecting data, birds were placed in PWRC’s dive tank two to three times a week for about two months so they could acclimate to the environment. Once birds were acclimated to the tank, trials to collect baseline dive data began, approximately two months before transmitter attachment trials commenced. A 1-m^2 PVC box served as the feeding zone on the bottom of the tank. Two ounces of mealworms were funneled onto the bottom of the box using a length of PVC pipe. Once the mealworms sank to the bottom, the PVC pipe was removed and two birds were placed in the dive tank. All trials were completed between 0600 and 1000 h. Birds remained in the tank for 1 hour, and all dives were documented. A video camera mounted approximately 20cm above the waterline on the back wall was angled at approximately 30° to record the entire dive tank, including the water column. Each bird was recorded for 10 one-hour time blocks, before and after transmitter attachment. Video of each dive was reviewed to determine four dive parameters: descent time, ascent time, total bottom time, and total dive time. Only complete dives (birds that successfully made it to the bottom of the tank) were included in the analysis. For each dive parameter, repeated measures ANOVAs were used to compare differences within each treatment (SAS 9.3).

6.3.2 Field Trials of Harnesses and Transmitters

6.3.2.1 Harness Deployment

After considering preliminary outcomes of captive experiments, we opted to test GPS-GSM transmitters (Cellular Tracking Technologies) and silicone harnesses on Northern Gannets, Red-throated Loons, and Surf Scoters in the field. All birds included in the trial were captured at night using night-lighting and netting techniques described in prior chapters. Once birds were caught, they were banded, evaluated for injuries or deformities, measured to aid in sizing of harnesses, weighed, and fitted with transmitters. Once the harness was attached, body feathers were fluffed and smoothed over the harness to aid in waterproofing and minimize impacts caused by handling.

6.3.2.2 Tail-tape Attachments: Transmitter Design Modification for Northern Gannets

Poor tag retention of harnesses by Northern Gannets was observed during the 2015 field trial, possibly due to harness removal by tagged individuals during preening. Therefore, in 2016 we opted to attach solar-powered GPS-GSM tags on Northern Gannets using a tail tape attachment method. To do so, we modified an established tail-tape tagging method (Garthe et al 2011) by creating an adapter with a 3-D printer to accommodate the solar-panels on our tags (Figure 6-5). The three centermost tail-feathers were selected for each transmitter placement. Tags were placed at the base of the shaft of the tail feathers, as close to the body as possible. Once properly placed each end of the adapter was taped three times in opposite directions using Tesa Tape, and finally secured with low profile cable ties (Figure 6-5). One cc of blood was taken to determine sex by Dr. Natalie Karouna-Renier at the Molecular Toxicology Lab, USGS-Patuxent Wildlife Research Center, Laurel, MD. Sex was determined by real-time Polymerase chain reaction (PCR) following the methods of Brubaker et al. (2011), with slight modifications, and using broadly applicable avian primers (Wang and Zhang 2009). All field procedures, including the deployment of harnesses and tail taped tags, were reviewed and approved under Institutional Animal Care and Use Committee number 2010-10 (USGS-PWRC).

6.4 Results

6.4.1 Captive Experiments to Test Harnesses and Transmitters

6.4.1.1 Transmitter Selection

Despite the addition of Sugru rails to raise the profile of the transmitters manufactured by Microwave Telemetry, Inc, transmitters were still easily covered by Surf Scoters during normal preening due to the narrow profile of the design (Figure 6-6). In addition, the external antenna on tags from Microwave Telemetry Inc. tended to be excessively preened, causing tag damage that affected performance. Therefore, we selected transmitters manufactured by CTT for the majority of captive and field trials. CTT tags had larger solar panels that were harder for birds to preen over, and did not require an external antenna.

6.4.1.2 Attachment Techniques

6.4.1.2.1 Suture Attachment

Dummy transmitters (*n* = 2) attached using stainless steel sutures in 2013 were removed within seven days due to an autoimmune response to the materials being used. Two of the 3 transmitters attached to Surf Scoters in 2014 using polyester sutures fell off within 60 days. The first came off on day 14, after most suture strands broke. The second transmitter started to come off on day 52, and was removed to avoid injury from drag caused by the failing attachment. The third transmitter remained securely attached through day 60, despite one strand of suture breaking. The sutures each broke at one of two places: either at the middle or the corner of the transmitter, caused by abrasion with the dorsal process. Birds that lost their transmitters displayed small scabs at the suture sites, which quickly healed. While birds experienced some temporary loss of waterproofing around the transmitter, no large abrasions occurred due to wear from the sutures or transmitter. Because of these cumulative impacts on bird health, and findings on poor tag retention, the suturing method was not used in the field.

6.4.1.2.2 Teflon Attachment

Four of five Teflon harnesses attached to Surf Scoters remained intact for the entire 60 day monitoring period. These harnesses showed no sign of wear or potential for breakage at any point. The fifth transmitter came off on day 28, with the Teflon worn though at the left rear anchor point. It is unknown what caused this wear and breakage. While retention was high, all birds outfitted with the Teflon harnesses lost substantial feather waterproofing and exhibited large abrasions underneath transmitters (Figure 6-7). Despite these effects, no birds showed signs of infection or severe health issues during the monitoring period.

6.4.1.2.3 Silicone Harness Attachment

All four silicone harnesses attached to Surf Scoter fell off within 38 days (retention times = 9, 12, 27, and 38 days). We subsequently repaired and continued testing these tags to improve their design. There were three different causes of harness failure, resulting in the harness disconnecting from the tag, or the harness breaking. First, the brass rings that attached the harness to the transmitter broke open (Figure 6-3). Second, corrosion of braided wire loops caused them to break. Lastly, the wire braid poked holes in the silicone and weakened it (Figure 6-8). Based on assessing causes of failure during initial tests, we made incremental improvements to harness design. First, we replaced brass connection rings with stainless steel. We then used polyethylene fishing line with heat shrink tape at the points of contact with the transmitter, instead of wire, to reduce abrasion of the harness where it meets the transmitter. The fishing line was knotted in various locations and set within the silicone while it dried in the mold.

In addition, we made several changes to the manufacture of the silicone harnesses and tag design. We changed silicone composition to provide greater flexibility (allowing greater elongation) with similar tensile strength and resistance to tearing. We also developed a new production method using a 6.3mm rounded mold, resulting in a more flexible harness that was 33% lighter than previous designs. Adequacy of fit and comfort (as inferred by time spent preening) of the improved harness design on Surf Scoters was examined during behavioral observations, which revealed that, although harness fit and comfort were improved, the manufacturer’s design of the GPS-GSM tag (including mounting points of tag to harness) caused feather wear and consequent loss of waterproofing. To account for this, we further improved tag design by integrating a smooth, hydrophobic surface on the underside of the transmitter that is in direct contact with the feathers, using a Teflon-based tape. This modification greatly reduced observed feather wear of tagged birds in captivity. We used this improved harness design during field tests of GPS-GSM transmitters attachments to three Surf Scoters in winter 2016 (see Field Trials of Harnesses and Transmitters section below).

6.4.1.3 Body Weights

All captive birds (sutures $n = 3$), Teflon harnesses ($n = 5$) and silicon harnesses ($n = 5$) tested in 2013-2014 exhibited weight loss immediately after tag attachment, regardless of tagging method used. This weight loss was followed by a slow increase towards pre-treatment levels for birds tagged using any attachment method. The average percent change in body weight for each tagging method ranged from a loss of 10.4% in the silicon treatment to a gain of 5.7% in the suture treatment. The weight losses were nonsignificant over the 60-day treatment period (F =1.41, d.f.=34, P =0.17) independent of treatment, and there was no difference between silicon and suture treatments (t = -0.67, df = 5.85, P =0.79), silicon and Teflon treatments (t=-0.39, d.f.=5.73, P =0.92), or suture and Teflon treatments (t=0.36, df = 5.96, =0.93).

6.4.1.4 Behavioral Observations

Preening significantly increased for Teflon harnessed birds during the 2013-2014 trials (q=3.71, d.f. =25, $P < 0.05$). All other behaviors were not influenced by treatments: sutures ($n = 3$), Teflon ($n = 5$) and silicon harnesses ($n = 5$). Additional observations in 2015 focused on the impact of the improved silicone harness design's influence on percent time allocated to feather maintenance on and off water. Surf Scoters preened significantly ($n = 12$, $P < 0.05$) more than controls. Treatment birds spent about 77% of their time on land versus the control birds' 55% ($P < 0.05$), and 45% of the time preening, while control birds spent approximately 31% of the time preening.

While the harness itself did not appear to have any physical effect, the transmitter casings caused skin irritation and abrasions on the back of several individuals (similar to Figure 6-7). This was not observed during the 2013/2014 trials, and was attributed to slight variations in external case texture. This result prompted us to incorporate Teflon tape as a hydrophobic and uniformly smooth surface on the underside of the transmitters (Figure 6-9) as our final design modification prior to the penultimate field trials in 2016.

6.4.1.5 Dive Performance

For most birds, the number of dives was greatly reduced after transmitter attachment. The average number of dives per bird before attachment for the suture, Teflon, and silicon treatments were 93.7, 149.7, and 113 respectively. These sharply decreased to 25.7, 22, and 27 dives per bird. Average descent and ascent times of tagged birds in 2013/2014 decreased with all attachment methods, but were not significantly different from one another (f=0.77, d.f.=41, p=0.8472; f=0.98, d.f.=41, p=0.504, respectively). All individuals with harnesses attachments spent more total time underwater (F=1.83, d.f.=41, p=0.003), whereas individuals with suture attachments had no significant difference in dive times compared with controls.

6.4.2 Field Trials of Harnesses and Transmitters

In March and April 2015, five Northern Gannets, ten Surf Scoters, and seven Red-throated Loons were tagged with harnesses in the Atlantic study area (Table 6-1). In August 2015, nine dummy transmitters and four active GPS-GSM transmitters were deployed on Northern Gannets using an improved version of the original silicone harness design. This work took place at Cape St. Mary's Ecological Reserve, Newfoundland. Field observations of tagged birds were made while they were on the nest. In March/April 2016 an additional three GPS-GSM transmitters were deployed on Surf Scoters using an improved version of the original silicone harness design, and 10 tail-tape transmitters were deployed on Northern Gannets in Chesapeake and Delaware Bays.

6.4.2.1 Surf Scoter

In April 2015, we deployed ten GPS-GSM transmitters on Surf Scoters using silicone harnesses. Scoters averaged 1090 ± 96 g (*n* = 5 females, 25 males). Tags were deployed at Cape Charles (VA), Pamlico Sound (NC), Delaware Bay (DE) and Choptank River (MD; Figure 6-10). Concentrations of scoters at our study sites were low, as migration was several weeks later than normal, potentially due to a series of strong winter storms and sustained freezing temperatures. We confirmed a 50% mortality rate of scoters tagged with GPS-GSM harnesses during 2015. All mortalities occurred on birds captured during the first four weeks of the study. Birds captured during these first four weeks (late February to early March) averaged 1032 ± 85g (*n* = 17), in contrast to birds captured late March to early April which averaged 1123 ± 50 g (*n* = 13), despite all birds being of similar age class and sex. This is an average of > 8% higher body mass for birds tagged in the later part of the deployment period, which in combination with milder environmental conditions after release, may have contributed to the much higher survivorship of those individuals.

Following harness improvements (Silicone Harness Attachment section above), three transmitters were deployed on adult male Surf Scoters (average body mass = 1260 g ± 30) in early April 2016 from Delaware Bay (SUSC_11; Table 6-2) and Chesapeake Bay (SUSC_12, SUSC_13; Table 6-2). All three immediately departed the wintering areas after tagging and followed the coast north to a major staging area in the Gulf of St. Lawrence (Figure 6-11). This movement pattern follows a similar migration pattern shown by most of the Surf Scoters implanted with satellite transmitters (*n* = 187; see Surf Scoter chapter of this report). During this northward migration, the tag of SUSC_13 stopped transmitting near Long Island, NY. It was never determined whether this bird died, the tag failed, or the tag came off outside of transmission range of a cellular tower. The remaining two tagged scoters migrated to Canada (Prince Edward Island and northern New Brunswick) presumably to the breeding areas. One of these tags (SUSC_11) stopped transmitting on 1 May after reaching Miscou Harbor, in northern New Brunswick. The fate of this bird is also unknown. The other (SUSC_12) was confirmed dead after it stopped moving in a marsh on southern Prince Edward Island (near Crapard). Upon recovery of the tag by the Canadian Wildlife Service, only one wing could be found. The harness and the tag were intact with no indication of wear. Without a carcass to examine, the cause of mortality could not be determined.

The average total distance traveled by all Surf Scoters (n=3) was 1232.7 km ± 499.5. Average speed of travel was 7.8 kph ± 10.5. The average maximum altitude recorded was 300.3 m ± 122.1, while average daily flight altitude averaged 12.9 m ± 13.6. All three Surf Scoters stayed in near-shore waters while migrating (Figure 6-11), and little overlap with proposed offshore wind energy areas was observed

(Figure 6-12). Despite small sample size, we obtained precise movement pathways of the three tagged scoters, showing some overland movements. One flew over the Delaware Peninsula while transiting between bays (Figure 6-12) then crossed both the Cape Wind and New York WEAs during northward migration. This individual, in addition to another tagged scoter, flew over land when moving from the Bay of Fundy to the Gulf of St. Lawrence. Two of the three tagged scoters also flew overland between the Chesapeake Bay and Delaware Bay (Figure 6-12).

One of the three Surf Scoters transmitters exhibited periodic gaps in time where the transmitter did not provide GPS locations as expected. No birds provided relocations beyond 27 days. This indicates that despite improvements to the fundamental design from the 2015 season, tag longevity remains an issue, and mortality is possible, though it is unclear whether it is tag-related. If mortality was tag-related, it could potentially be due to external tags interfering with bird buoyancy and as a result, diving behavior. It could also be associated with persistent problems with the harness interfering with waterproofing.

6.4.2.2 Red-throated Loon

Project partner, Biodiversity Research Institute (BRI) captured and deployed seven GPS-GSM transmitters on loons using silicone harnesses during April-March 2015. Birds averaged 1800 ± 194g, lighter than average weights of loons captured during prior field seasons 2014 (1895 ± 247g) and 2013 (1816 ± 211g). High variance in weights of the loons led to difficulties with harness fit. Three of the seven tagged loons died within two weeks of tag deployment. Carcasses were recovered and showed signs of undernourishment, despite the harness being fully intact. A fourth tagged loon stopped moving in a remote North Carolina marsh around 13 days after deployment. While this carcass could not be recovered, it is also assumed to have died, though it is also possible that the tag came off. The tag of a fifth loon was recovered nine days after deployment. Based on the location of the tag, far up a river bank, it is also likely that this bird died, though no carcass was found. The last two tags stopped transmitting within 15d of deployment. No carcass or tags were ever found, and bird fates are unknown. The high mortality rate just after tagging, combined with abnormal behavior observed immediately post-tagging in nearly all tagged individuals (i.e. loons went well up into rivers and reduced movement, rather than moving steadily along coastal routes as observed with PTT-tagged birds), suggested that the harness method adversely affected loons. Therefore, no new transmitters were deployed in 2016.

6.4.2.3 Northern Gannet

During late March 2015, BRI captured five Northern Gannets (3620 ± 216g) near Cape Charles, VA and fitted them with GPS-GSM transmitters using silicone harnesses. All tags stopped transmitting within 11 days of deployment, and bird fates were undeterminable.

From August 23rd - 29th 2015, nine silicone harnesses with non-functional replica (“dummy”) transmitters were attached to breeding Northern Gannets on a mainland nesting area to the west of the main colony on Bird Rock at the Cape St. Mary’s Seabird Ecological Reserve, Newfoundland, Canada (Figure 6-13). The harnesses remained on the birds from a few days to a week. During the brief time that the Northern Gannets remained at the colony, one harness was known to have been shed, one was broken, and one harness was removed from a bird before release as it was too large and loose for the animal. As all harnessed birds abandoned the colony, it was not possible to obtain further information on harness/tag retention. From September 24th - 29th, four active GPS-GSM tags were attached to Northern Gannets at the same site after improvements were made to allow greater flexibility to harness fit. One of these harnessed birds retained its tag for 13 days. This bird was found dead with harness and tag on a beach in Argentia about 75 km of Cape St. Mary's, an area where Northern Gannets often forage. The cause of mortality was undetermined, and the bird appeared to be in good body condition. Two Northern Gannets retained harnesses for at least five days, and the other harnessed Northern Gannet retained its device for three days at which time it abandoned the colony. Harnessed Northern Gannets with CTT tags actually performed better (though not adequately) compared to harnessed Northern Gannets with dummy tags. Though some preliminary tracks were obtained from these birds, we conclude that Northern Gannets are not an appropriate species for external harness attachments and we used the tail-tagging attachment method for all subsequent GPS-GSM deployments.

In early April 2016, 10 GPS-GSM transmitters were deployed on Northern Gannets (7M: 2F: 1U), using tail tape attachments, in Delaware Bay (n = 7) and Chesapeake Bay (n = 3; Table 6-3). Average male body mass was 3364 g (± 287) and female body mass was 3825 g (± 177). Tags successfully transmitted Northern Gannet locations from 21 to 115 (± 34) days, with transmissions likely ceasing prior to the end of predicted battery lives due to natural tail feather molt and associated tag loss. Of the 10 tagged Northern Gannets, seven transmitted movement information throughout their entire northward migration and were confirmed in the vicinity of colonies in eastern Canada within 18 (± 4) days of deployment. Tags attached to the other three birds stopped transmitting while those individuals were likely moving to colonies (i.e. last known location was within a common flight pathway of known colonies, determined from prior PTT flight routes).

Six tagged Northern Gannets travelled to Bonaventure Island (Quebec), the largest North American Northern Gannet colony, comprising more than half of all breeding pairs in North America (Chardine et al. 2013). One Northern Gannet travelled to Grosse Island and Magdalen Islands (Quebec), the second largest North American Northern Gannet colony. One (NOGA_16, Table 6-3) stopped transmitting off the northeastern tip of Cape Breton, Nova Scotia. No cellular reception exists between this point and some of the more remote Northern Gannet breeding colonies. Hence, it is possible that this bird ended up at a remote northern colony and then shed its tag before it could transmit its locations. An additional 2 transmitters likely fell off during migration. Both were lost off the coast of Long Island, after remaining on the birds for 18 and 24 days. Both tagged birds stopped transmitting locations prior to northward migration. However, one (NOGA_12, Table 6-1) traveled south after capture to the Florida coast, then returned to waters off Long Island, within 10 days travelling ~2300 km during the process.

During migration, tagged individuals averaged 2874.3 km (± 821.9) total distance traveled, with a daily distance averaging > 161 km (± 166), and average movement speed of 7.0 kph (± 1.6). Average maximum altitude was 212.5 m (± 136.0), while average daily flight altitude was 9.1 m (± 1.6; Figure 6-14). There was no significant difference in distance from shore and diurnal period (day/night) (f=0.40, p=0.5485). Six tagged Northern Gannets traveled across a total of 32 WEAs and Lease Areas during migration. Tagged Northern Gannets used waters within the Massachusetts Lease Areas (Figure 6-14, North/South, OCS-A 0500) and Delaware Lease Area, more frequently than any other WEAs or lease areas crossing them multiple times over a 6-day period. In addition, one tagged individual (NOGA_12, Table 6-3) crossed the Virginia Lease Area, North Carolina WEA, and South Carolina Call Area and flew south to Florida before returning to the study area. Analyses using Hidden-Markov models (Appendix B) indicate that tagged Northern Gannets engaged in multiple behaviors while in WEAs, including roosting, foraging, high-altitude transiting, and day-time loafing. In addition, COX Proportional Hazards regression modeling indicated that select weather covariates did not significantly influence presence offshore (Appendix B).

Despite retention duration limitations inherent in tail tape attachment, tag retention was high, compared to silicone harnesses. However, periodic GPS malfunctions were noted for five of the 10 tags. Overall, the units successfully logged a location 91% (±7%) of the time. When tags failed to log locations, entire weeks were sometimes missed, and this performance was highly variable across tags.

6.5 Discussion

Reducing potential impact of tags on the behavior of wildlife is a challenge for biologists, regardless of the type of transmitter used. Not knowing the influence a tag has on an animal's behavior can lead to data that is biased towards atypical movement characteristics (including timing, occurrence, and behavior (Taylor et at 2001, Vandenabeele 2014, Perry 1981) or reduced overall fitness (Barron et al 2010, Godfrey et al. 2003) that could contribute to tag-related mortality several months or even years after deployment (Dzus and Clark 1996, Robert et al. 2006). This project used captive trials to examine how external tags of different designs influenced behavior in captive birds, and applied this knowledge to develop iteratively optimized designs so solar-powered GPS-GSM tags could be deployed in field trials.

Although our penultimate designs for external silicone harnesses were not effective for two of three diving bird species examined, the study provided valuable insight into how harnesses may have impacted the birds, which will provide future studies with data to evaluate improved designs. For most birds, the failure of harnesses as an effective means of attaching transmitters to diving birds was likely the result of a complex interplay of hydrodynamic properties of the tags, foraging dive depths, feather compression, and waterproofing – all of which led to increased time spent preening and a reduced time spent foraging or resting.

With Red-throated Loons in particular, we suspect that the harness and external transmitter directly impeded their ability to forage. Given that loons actively pursue prey fish at high speeds (Polak and Ciach 2007), any negative changes in buoyancy and drag would result in more energy being expended to maintain depth or speeds, and may hinder the ability of the animal to achieve such speeds at all. Although we don't have direct observations to support this hypothesis, the emaciated state of the tagged loon carcasses we recovered suggests that birds were unable to forage after deployment. Furthermore, tag hydrodynamics may be exacerbated by the depth and duration of loon foraging bouts, during which natural compression of the bird's feather structure (Lovvorn and Jones 1991) may have further exposed the tag body to the flow of water, increasing drag (Lovvorn 2001).

Northern Gannets did not retain silicone harnesses beyond seven days, leading us to conclude that the silicone harness simply wasn't strong enough to persist with the birds preening and/or picking at their tags with their large sharp bills. The adapted tail-tape method proved successful for attaching external tags to Northern Gannets, and though longevity of tag deployment was compromised by tail feather molt, the tagging technique may be the best way to collect data on fine-scale movements of the birds over a short period of time. We observed some difficulties in tag function during the 2016 field deployments that was likely attributable to manufacturing variability in components by Cellular Tracking Technologies, and/or slight variation in bird behavior or tag placement that reduced the effectiveness of the satellite antenna in successfully recording location data during a recording interval (60 sec). Cellular Tracking Technologies is currently working on design modifications to GPS-GSM tags as part of a newly funded project (USGS & USFWS) aimed at improving tag performance for future tracking of this species, along with further improvements to weight distribution.

The effectiveness of using silicone harness attachments to attach external tags on Surf Scoters was inconclusive, but we believe it still shows promise. Unlike Red-throated Loons, Surf Scoters dive for sessile prey and expend energy to remain at the bottom for extended periods while foraging (Berlin 2008). As a consequence, any changes in buoyancy caused by tag attachment, or impacts to feather waterproofing remains a serious concern, as demonstrated by our captive work which showed increased preening among tagged birds. However, improvements to the tag and harness design are obtainable as technology and manufacturing processes continue to improve.

New manufacturing techniques, such as rapid 3-D printing prototyping (Petrick and Simpson 2013), are making fast and customizable in-house processing a reality, and are changing the viability of creating new external tag designs that address a species' unique needs (preening behaviors, wing loading, etc.). New materials science is leading to advances in new superhydrophobic materials (Zhou et al. 2012) that may improve issues of external tags degrading the natural waterproofing of feathers under the tags. In contrast, while advances in the design of implantable transmitters may decrease tag weight and increase tag longevity, these technological improvements will never negate the need for an invasive surgical procedure to implant tags, which can influence mortality (see Chapter 5). Thus, we strongly encourage continued research into new techniques for attaching external tags on diving birds with the goal of an overall reduction in handling, mortality, and tagging bias in the future.

Despite limited sample sizes, our pilot research demonstrated the utility of recently-developed GPS-GSM technology in answering key questions relevant to evaluating impact and mitigation strategies for migrating birds on and offshore. GPS-GSM tags provide location data at a precision and frequency that permits a more complete understanding of fine-scale movement patterns of marine birds. Our preliminary data provided novel data on location, speed, and a rough idea of flight height through a 24 hour day during spring migration, and finer-scale locations of birds in and around specific WEAs and Lease Areas. Although low sample sizes prevented us from conducting a robust analysis, we were able to undertake exploratory modeling efforts with a subset of individuals (Appendix B). This analysis explores how detailed GPS data could be used to infer how weather covariates and time of day influence flight behavior, and potentially could be used to predict occurrence patterns in the offshore environment.

We conclude that external GPS-GSM transmitters are a new and powerful tool that can be used to better understand movement patterns and behavior on a finer scale than previously possible. However, more study is needed on effectively attaching these external transmitters to diving birds for more than a few months. Testing of harnesses on birds in captivity allowed us to frequently evaluate and improve the design for deployment in the field. While 2015 field deployment was unsuccessful, a number of variables, including colder than usual capture temperatures and unusually underweight individuals, may have biased the outcome of the field test. Field deployments in 2016 also underperformed, but the sample size was very small, and the fates of some tagged individuals were inconclusive. Although a reduction in harness weight and bulk between design iterations improved the "comfort" of the harness, additional modifications to harness and tag design are clearly needed.

Moving forward, we recommend testing the application of modern manufacturing techniques such as rapid 3-D printing, injection molding, and carbon-fiber materials. New research on hydrodynamic properties of tag design and placement is particularly critical, especially given the complex interplay between pressure, speed, compression and turbidity (Lovvorn and Jones 1991, Taylor et al. 2001) that diving birds balance with when foraging at depth. For other marine bird species that do not regularly dive (including surface feeders including fulmars, gulls, etc.), this technology shows incredible promise for future studies that seek high-precision, real-time data that can be used to link environmental covariates with movements in the offshore environment.

Table 6-1. Total number of GPS-GSM transmitters deployed on each species (NOGA = Northern Gannet, SUSC = Surf Scoter, RTLO = Red-throated Loon) in 2015 and 2016.

	NOGA	SUSC	RTLO	Total
2015	**10**	**10**	**7**	**27**
Cape Charles, VA	6	2	6	13
Cape St. Mary, NL	4			4
Cedar Island, NC		2	1	3
Choptank, MD		3		3
Slaughter Beach, DE		3		3
2016	**10**	**3**		**13**
Choptank River, MD	3	2		5
Delaware Bay, DE	7	1		8
Grand Total	**20**	**13**	**7**	**40**

Table 6-2. Summary statistics of Surf Scoters deployed during the spring 2016 field season.

Animal_ID	Sex	Date deployed	Date of Last Transmission	Tag Longevity[1] (days)	Max altitude (m)	Median altitude (m)	Total distance (km)	Avg. speed (kph)	Fate
SUSC_11	M	4-Apr-16	1-May-16	27	431.3	4.6	1332.8	23.4	Unknown; possibly made it to breeding area
SUSC_12	M	9-Apr-16	4-May-16	25	319.2	2.4	1675.6	4	Mortality; recovered by CWS
SUSC_13	M	8-Apr-16	25-Apr-16	17	314.7	2.4	691.3	2.1	Unknown fate; tag failed around Long Island
Average				23	300.3	3.1	1232.7	7.8	
Std. Dev.				5	122.1	1.3	499.5	10.5	

[1] Days till tag stopped transmitting either due to mortality, tag loss, or tag stopped transmitting.

Table 6-3. Summary statistics of Northern Gannets deployed during the spring 2016 field season. Altitudes and speeds calculated from relocations within the mid-Atlantic study area, before birds had arrived at breeding sites.

Animal_ID	Sex	Date deployed	Arrival at breeding area	Date Last Transmit	Tag Longevity[1] (days)	Max alt. (m)	Median alt. (m)	Total dist. (km)	Avg. speed (kph)	Fate
NOGA_10	U	30-Mar-16	14-Apr-16	23-Jul-16	115	293.3	6.5	2554.3	8.0	Bonaventure Isl. colony
NOGA_11	M	1-Apr-16	21-Apr-16	20-Jun-16	79	245.2	5.8	3136.0	6.3	Grosse-Île colony
NOGA_12	M	2-Apr-16	-	24-Apr-16	22	181.0	3.7	3572.5	6.9	Transmitter likely lost (NY)
NOGA_13	M	2-Apr-16	26-Apr-16	15-May-16	43	145.0	4.6	4427.4	8.0	Bonaventure Isl. colony
NOGA_14	M	2-Apr-16	21-Apr-16	14-Jun-16	73	299.8	2.9	2811.4	6.2	Bonaventure Isl. colony
NOGA_15	M	2-Apr-16	23-Apr-16	28-Apr-16	26	112.7	4.6	3088.1	8.8	Bonaventure Isl. colony
NOGA_16	M	4-Apr-16		26-Apr-16	22	137.1	2.1	2503.8	4.9	Unknown - out of cellular range
NOGA_17	F	6-Apr-16		19-Apr-16	13	82.9	3.2	1324.4	4.5	Transmitter likely lost (NY)
NOGA_18	F	8-Apr-16	26-Apr-16	10-Jun-16	63	529.3	4.9	3069.3	7.3	Bonaventure Isl. colony
NOGA_19	M	10-Apr-16	21-Apr-16	3-May-16	23	99.2	2.4	2255.8	9.5	Bonaventure Isl. colony
AVG.					48	212.6	4.1	2874.3	7.0	
ST. DEV					33	136.0	1.4	821.9	1.6	

[1] Days till tag stopped transmitting either due to mortality, tag loss, or tag stopped transmitting.

Figure 6-1. Relative size of solar panel on Microwave Telemetry, Inc. (with external antenna) and CTT transmitter

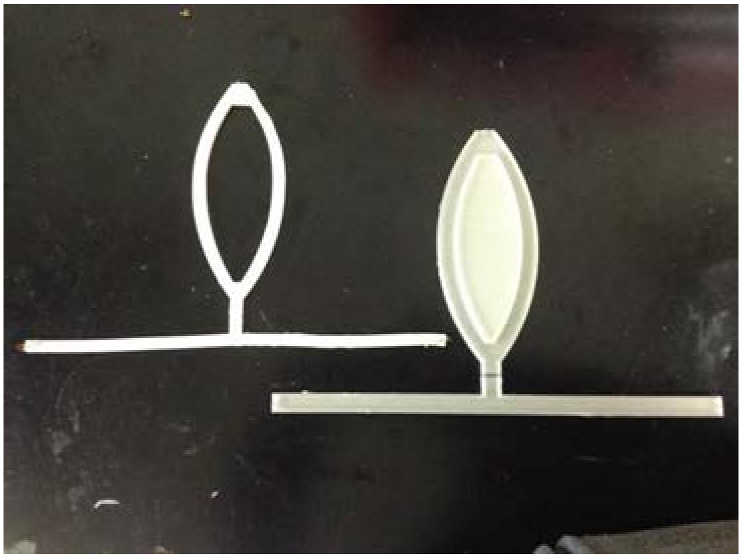

Figure 6-2. 3-D printed mold and the resulting silicone harness.

Figure 6-3. Method of attaching silicone harness to transmitter using stainless steel rings that failed within 60 days.

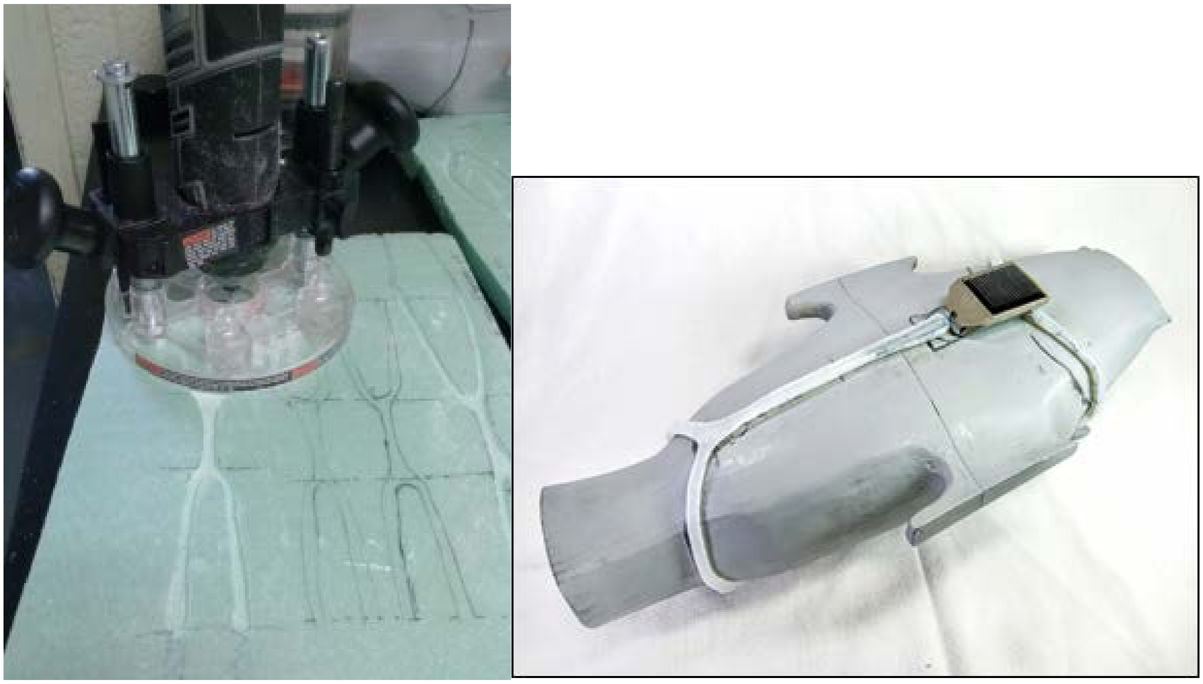

Figure 6-4. Improved 2015 silicone harness design using a 6.3mm router and 3-D printed Northern Gannet model.

Figure 6-5. Left: Tag adapter created with a 3-D printer, designed to securely attach solar-powered transmitters close to tail feathers close to the body of gannets. Right: finalized package attached to NOGA_12.

Figure 6-6. Male Surf Scoter with the Microwave Telemetry, Inc. transmitter completely covered with feathers.

Figure 6-7. Skin irritation and feather breakage on captive-tagged Surf Scoter caused by Teflon harness after 60 days of wear.

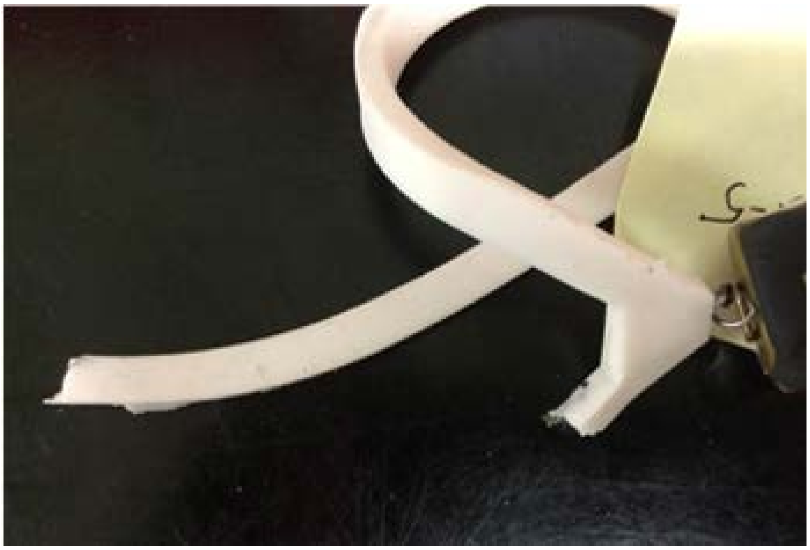

Figure 6-8. Image of the breakage of silicone harness at junction with end of stainless steel wire.

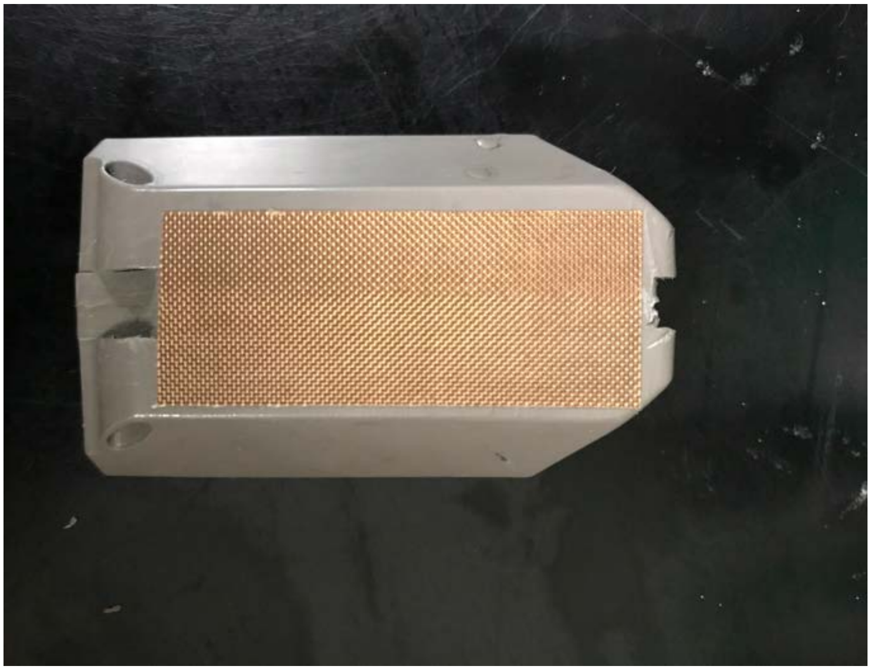

Figure 6-9. A simple strip of Teflon tape was used to provide a uniformly smooth hydrophobic barrier between transmitter and feathers.

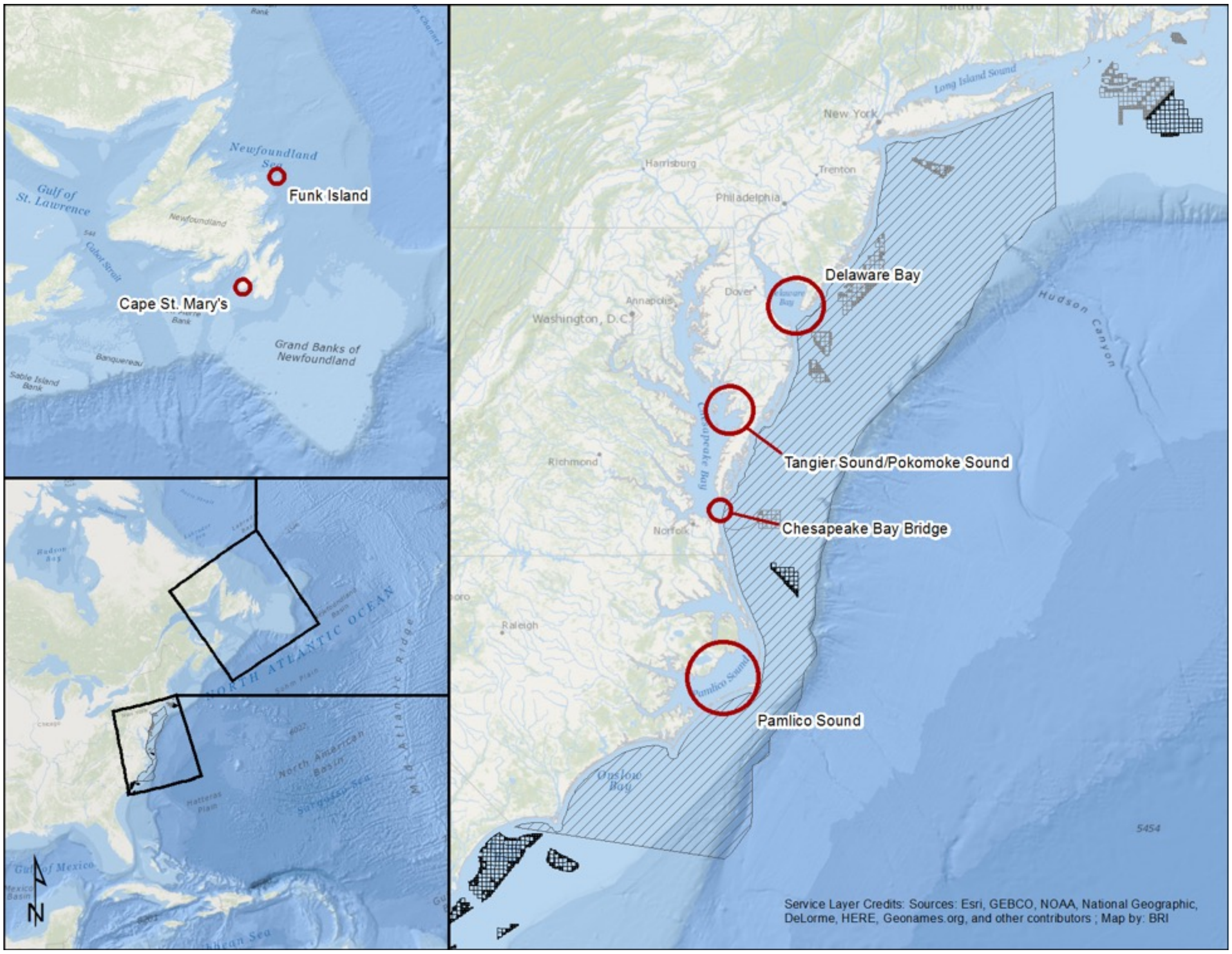

Figure 6-10. Capture locations within the Mid-Atlantic study area (hatched area, right map) and at two breeding colonies in Newfoundland, Canada (top left map) for 2015 and 2016 field deployments of GPS-GSM transmitters. The federally designated Wind Energy Areas (WEAs) within and surrounding the study area are also included – light gray blocks = BOEM Lease Areas, dark gray blocks = BOEM Wind Planning Areas.

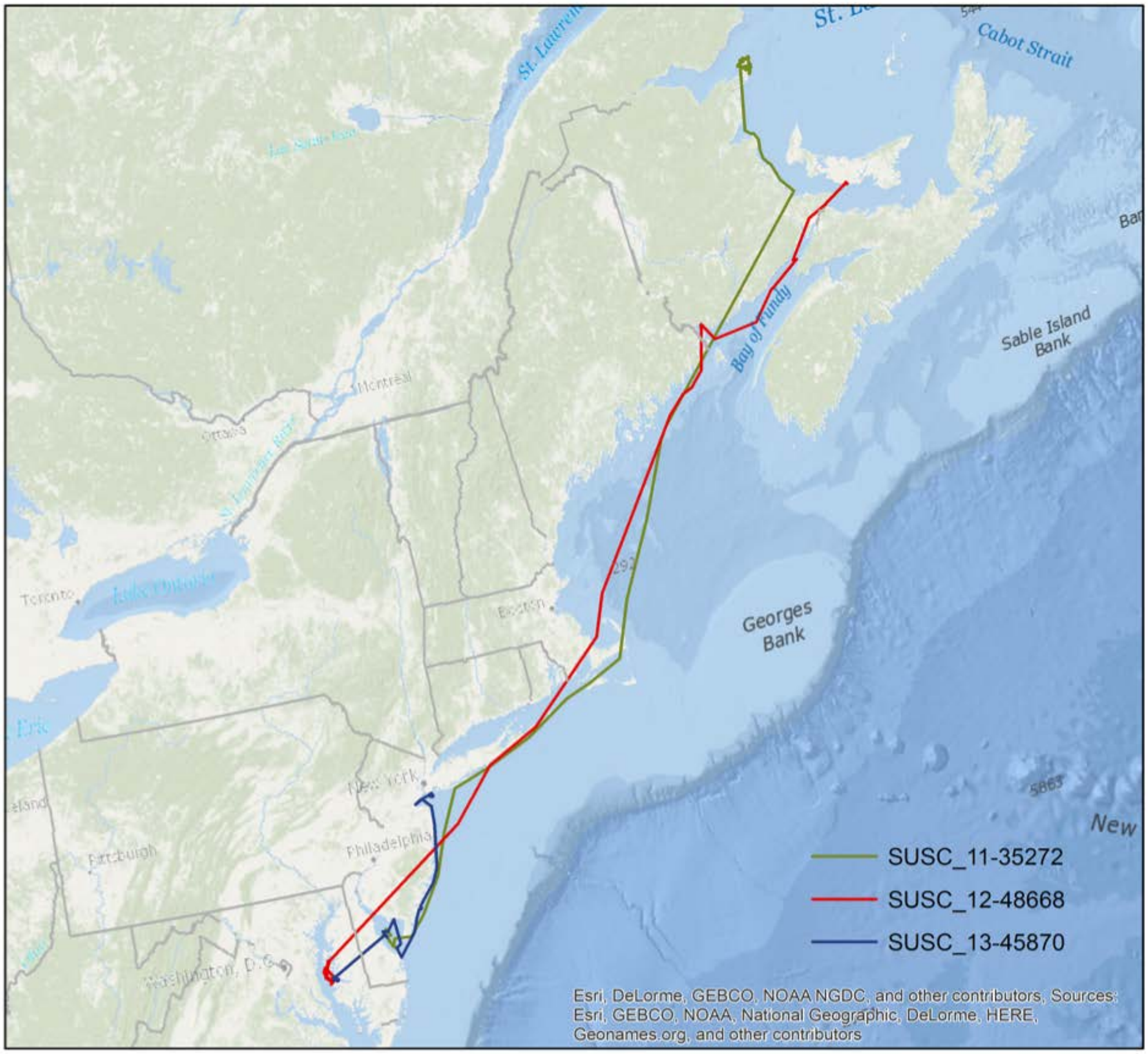

Figure 6-11. Migratory route of three Surf Scoters tagged with GPS-GSM transmitters over the course of 2 weeks.

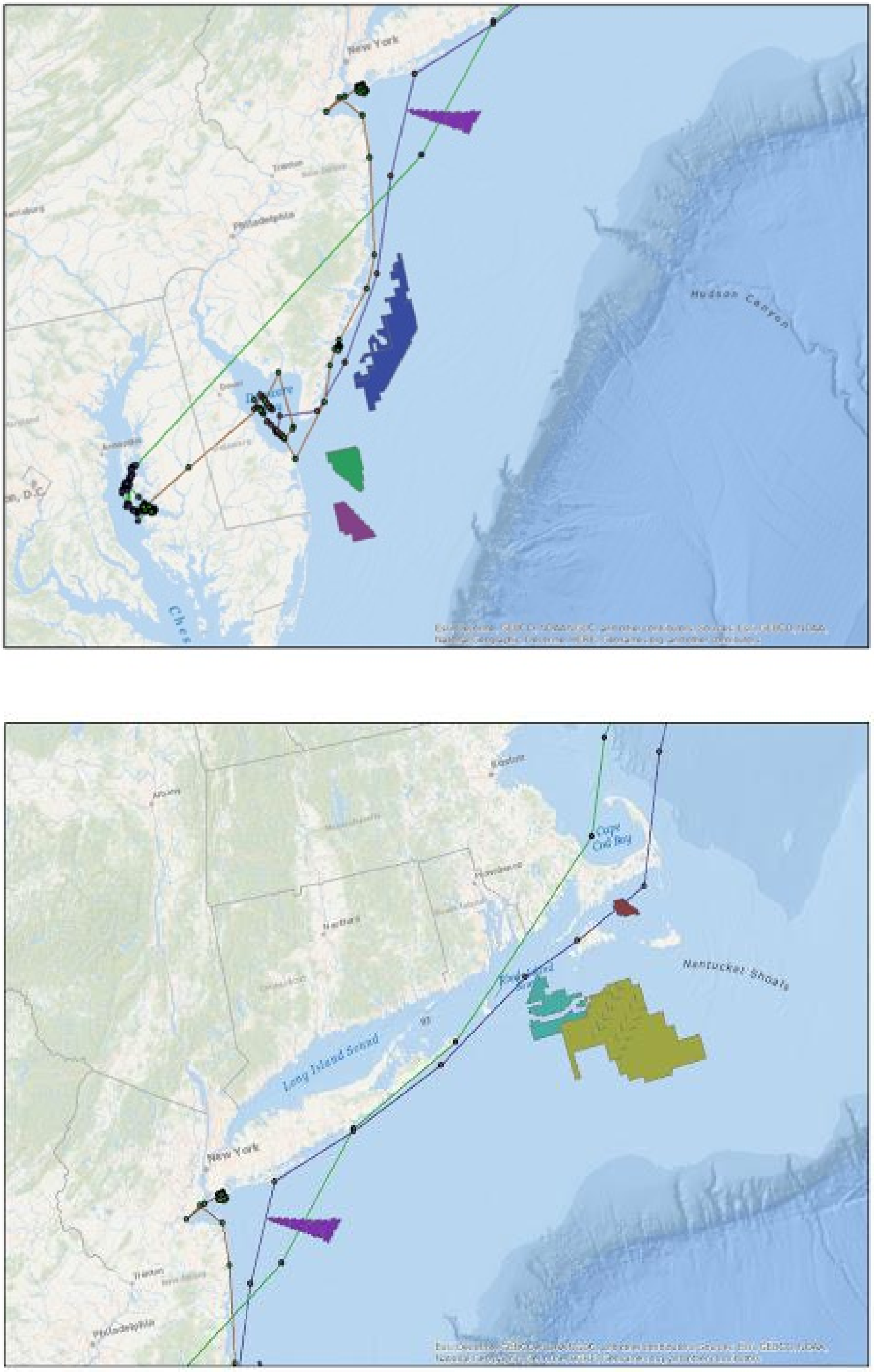

Figure 6-12. Movements of three adult male Surf Scoters tagged with GPS-GSM transmitters over a two week period during their northerly migration in relation to proposed offshore wind energy areas in the mid-Atlantic region. Shaded regions show proposed wind energy areas.

Figure 6-13. Cape St. Mary's Seabird Ecological Reserve, Newfoundland. Circled area shows a yellow-banded gannet which carried a harness that came off the bird.

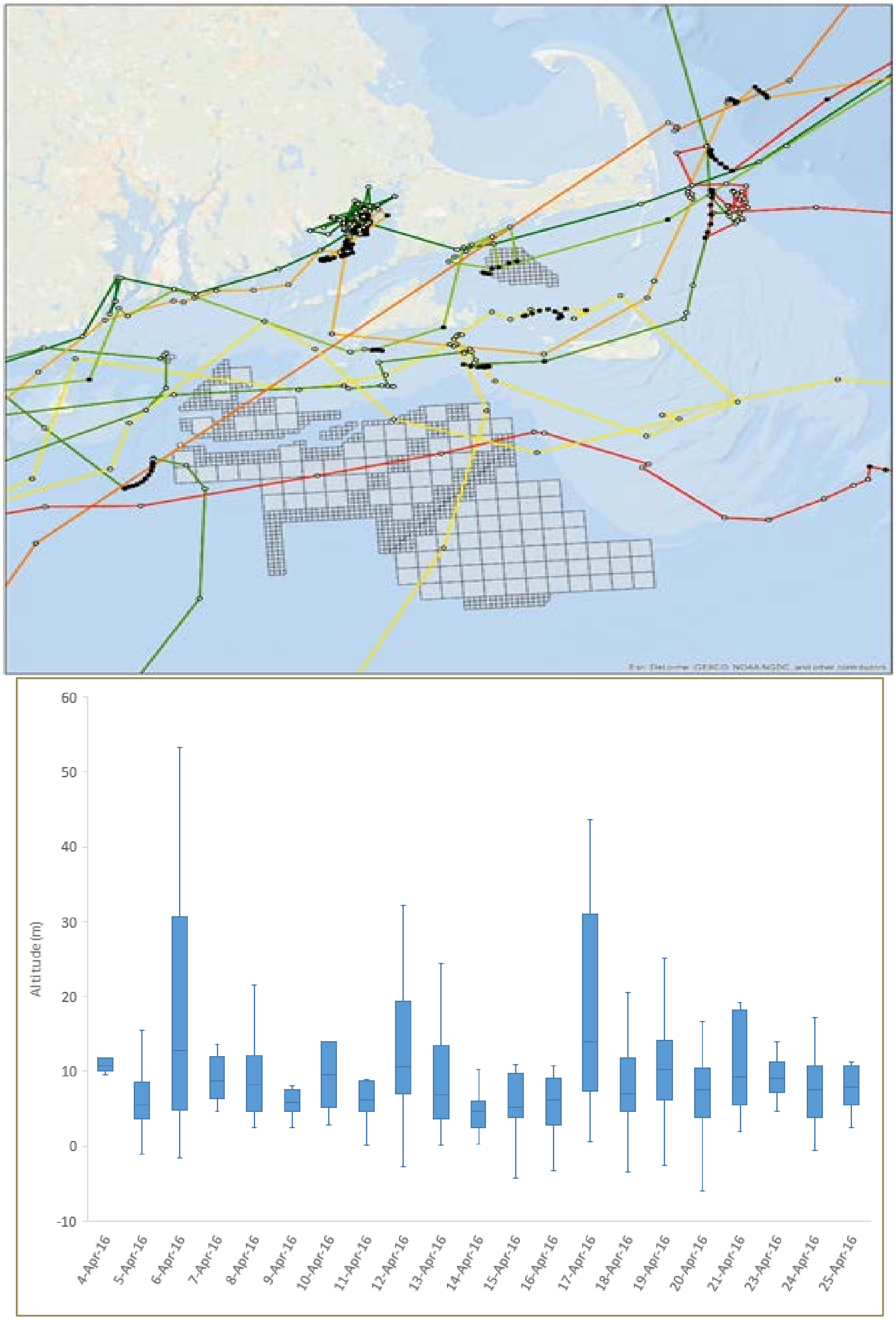

Figure 6-14. Daily movements (above) and average flight altitudes (below) for seven Northern Gannets around Lease Areas off Rhode Island and Massachusetts during April 2016. Twenty-four relocations were recorded per day for each bird (one each hour). Gray circles indicate locations taken during the day, while black points represent nighttime locations. Box and whisker plot shows average daily altitude, first and third quartiles, and standard errors.

Appendix B: Case-study of GPS-GSM data using Hidden Markov and Cox Proportional Hazard modeling of covariate effects

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Introduction

The data obtained through the 2016 pilot study using GPS-GSM transmitters is the first of its kind to describe the migration of Surf Scoters and Northern Gannets along the Atlantic coast. This appendix presents preliminary and novel observations of the offshore movements of individual animals that demonstrate the potential utility of this type of high-resolution data to investigate the influence of weather on migratory behavior (Figure B-1).

For this analysis, we selected Hidden Markov Models (HMM) and Cox proportional-hazards regression to model weather covariates and observed movement behavior. Due to small sample sizes, both analyses had little statistical power, so the results should be viewed as preliminary. However, they demonstrate the potential utility of GPS-GSM data in future studies, and explore different analytical techniques that can answer key questions about how birds interact with wind and weather in an offshore environment.

HMMs are useful tools for modeling time-series data where multiple, non-observable variables contribute to an observed state sequence (Langrock et al. 2012). The method is particularly relevant in the modeling of animal movement data, where the animal's location in space and time depends on a series of unknown internal cues and environmental variables. When relocation data are collected at high precision and regular time intervals (such as the hourly data collected from the GPS-GSM tags), HMMs allow for the analysis of animal movement by breaking down observed relocations into discrete underlying states that broadly reflect patterns of behavior. These behavioral states are based off a series of unknown external and internal influences the animal has negotiated.

This technique has been used extensively in the behavioral mapping of several species of mammals and birds (e.g. Franke et al 2006, Dean et al. 2012, Langrock et al. 2012, 2015, McKellar et al. 2015). These papers observe empirically-derived behavioral states, the product of the HMM analysis, as a tool to describing ecosystem function, and to infer the potential basis of observed behavioral shifts. This is done through examination of state-switching in response to different external variables, including weather covariates such as wind speed, wind direction, precipitation and pressure.

Methods

Hidden Markov Models (HMM)

By adapting Langrock et al. (2012) we conducted an HMM analysis using R package moveHMM 1.3 (R version 3.3.1, Michelot et al. 2016) on movement data derived from four tagged Northern Gannets that successfully migrated from our capture sites at Chesapeake or Delaware Bays to the breeding grounds during the 2016 spring migration (Figure B-1). Other birds tagged with high-resolution GPS-GSM tags were excluded due to limitations in data quality issues with the tags (in this case, if data were missing for >12 consecutive hours; see Chapter 6), or because the animal did not successfully migrate out of the study area before signal was lost.

Both two and three-state models were fitted to data that incorporated associated surface environmental covariates at the time of the observation. This included precipitation rate (mm/h), pressure (mbar), visibility, U (east/west) and V (north/south) components of wind speed (km/h), distance from shore (km), and time of day (NCEP NARR/Movebank, accessed April 2017). Top performing models were determined by ranked AIC and assessed for goodness of fit using analysis of pseudo-residuals against theoretical standard normal distributions (Patterson et al. 2009, Basson et al. 2012, Langrock et al. 2015).

Cox Proportional-hazards models

We adapted a Cox proportional-hazards regression model (Cox 1972, Loring 2016, Therneau & Grambsch 2000) to examine the influence of atmospheric covariates on seabird presence or absence > 3 nautical miles (nm) offshore using Proc Phreg procedure Breslow method in SAS (SAS/STAT 2016). Cox provides a useful way of analyzing a categorical 'risk' (in this case, the presence of a bird > 3nm offshore) and the relative significance of covariates bearing on that risk over time. For our analysis, the programming statement method (Powell et al. 2012) was used to incorporate time dependent covariates. Individuals that failed to complete migration to Canadian waters or were lost due to transmitter failure were considered right-censored, which in survival analysis framework is similar to an individual being removed from the study before the event occurs (SAS/STAT 2016). Best fit models were determined using stepwise selection and covariates were considered significant at the 5% level.

Results

HMMs favored a three-state model to describe observed movement patterns of Northern Gannets that met data quality criteria and successfully left the study area during spring migration to Canada. The model converged on three modes of behavior, roughly described as 1) short step-length with a highly stochastic turning radius (State 1, 'Active'), 2) short step-length with low turning radius (State 2 'Sedentary'), and 3) longer step-lengths with normally distributed turning between relocations (State 3 'Transiting'). The model assigned all relocations observed > 3nm from shore to state 3 'Transiting', while near-shore behavior was a proportional mix of all three behavioral states (Figures B-2 and B-3). Transition probabilities between states were also evaluated for the top-ranking model. Of 44 mixed-effects models tested, 'Distance from Shore' was the strongest factor describing state-switching behavior across 1823 observations as birds migrated along the Atlantic coast. Fifty-five percent of animal relocations were assigned as State 1 ('Active'), whereas movement events that were characterized with longer distances between successive relocations and normally distributed turning angles ('Transiting') were assigned to 15% of observed relocations, and birds were sedentary 30% of the time. The probability that birds would transition from Sedentary to Active (2 → 1) behavioral modes was negatively correlated to distance from shore, whereas the probability that a bird would remain in either ‘Active’ (1 → 1) or ‘Transiting’ (3 → 3) behavioral modes showed an increased positive correlation with distance from shore. Cox proportional-hazards analysis showed no significant influence of any tested weather covariates on the presence of the bird offshore.

Conclusion

Despite a small sample size, the HMMs results suggest that behavioral state-switching near-shore is driving birds into a movement mode (State 2, ‘Transiting’) that brings them into Federally-regulated offshore waters. Although none of the examined covariates (Precipitation Rate, Pressure, Visibility, U and V components of wind speed, distance from shore, and time of day) predicted greater exposure to the offshore environment, a larger sample size across several years of study would help elucidate whether the weather experienced by these four Northern Gannets in April 2016 was typical of the migration period. As a result of our low sample size, direct comparisons with similar studies should be undertaken with caution. For example, recent efforts using nanotags within the Southern New England - New York Bight region on Common Terns (Loring 2016) suggest a significant influence of wind speed and visibility on crossing events of proposed Wind Energy Areas, but these conclusions were made on a sample of 116 individuals across the season. While we were unable to investigate the influence of age and sex (80% of the Northern Gannets we captured in 2016 were adult males), these covariates could help us assess the influence of demography on movement behavior in future studies, especially given the importance of endogenous rhythms to timing of migration (Fifield et al 2014). Our results do affirm some of the conclusions of Fifield et al. (2014) which hypothesized minimal movements at night. We recommend a larger sample size and deployment of tags earlier in the winter to capture movements across the entire season for future studies on Northern Gannets along the Atlantic coast. This would likely generate a more refined predictive model of the influence of weather on exposure to planned offshore energy development activities on the Atlantic coast.

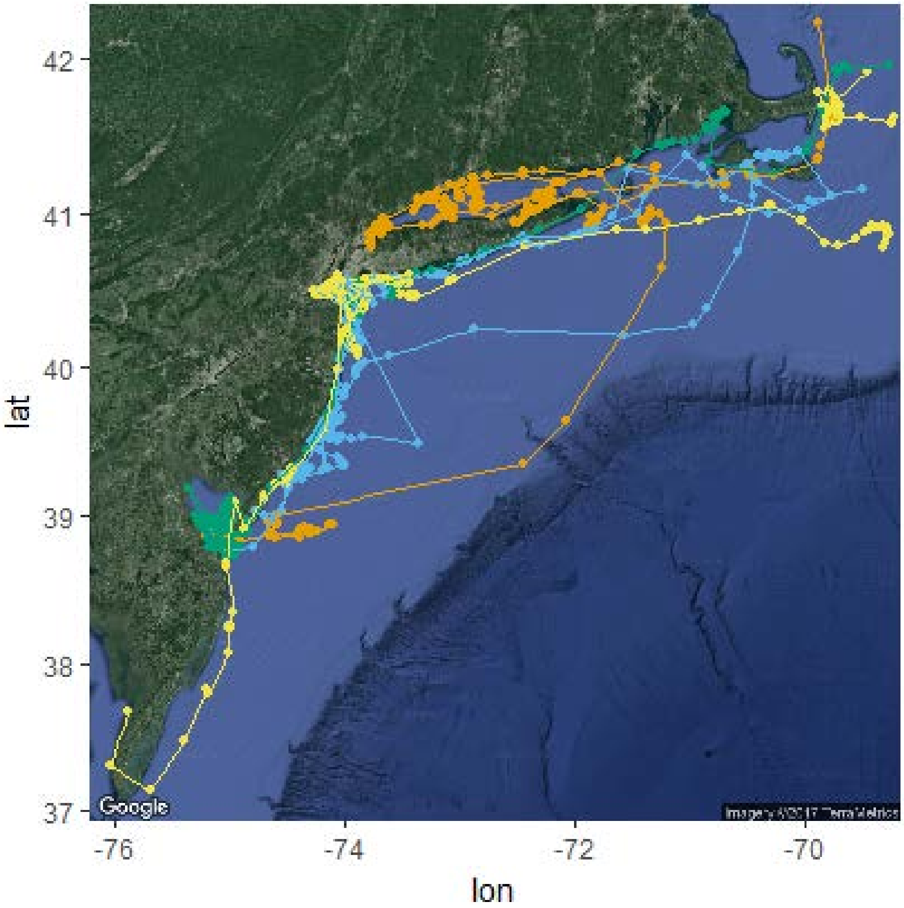

Figure B-1. Migratory pathways of four Northern Gannets along the Atlantic coast during spring migration included in the HMM analysis.

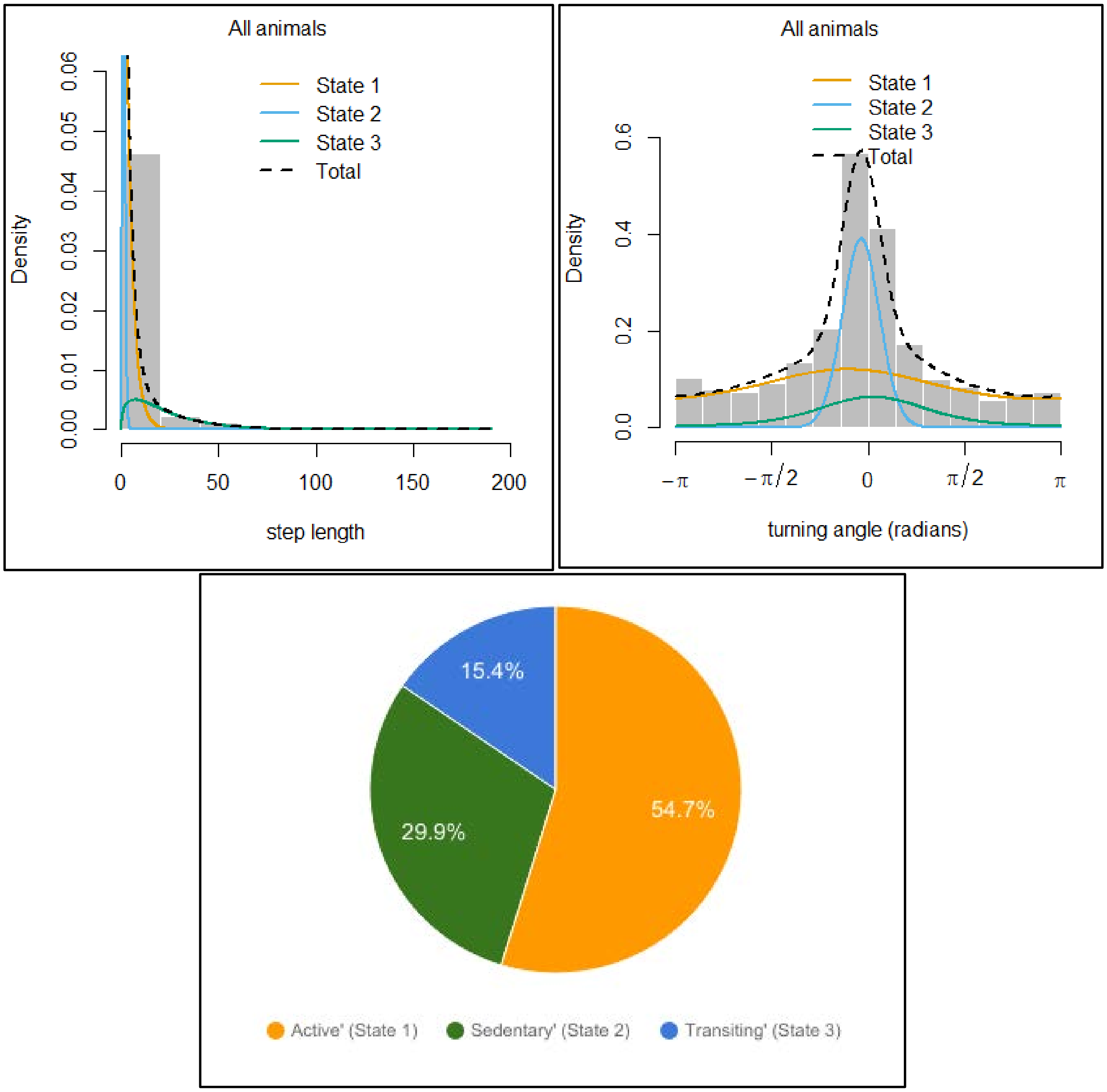

Figure B-2. Top: Distribution of behavioral states in relation to distance traveled between successive relocations (step length in km) and turning angle (radians). Bottom: Proportions of behavioral states determined by HMM analysis (see text for state definitions).

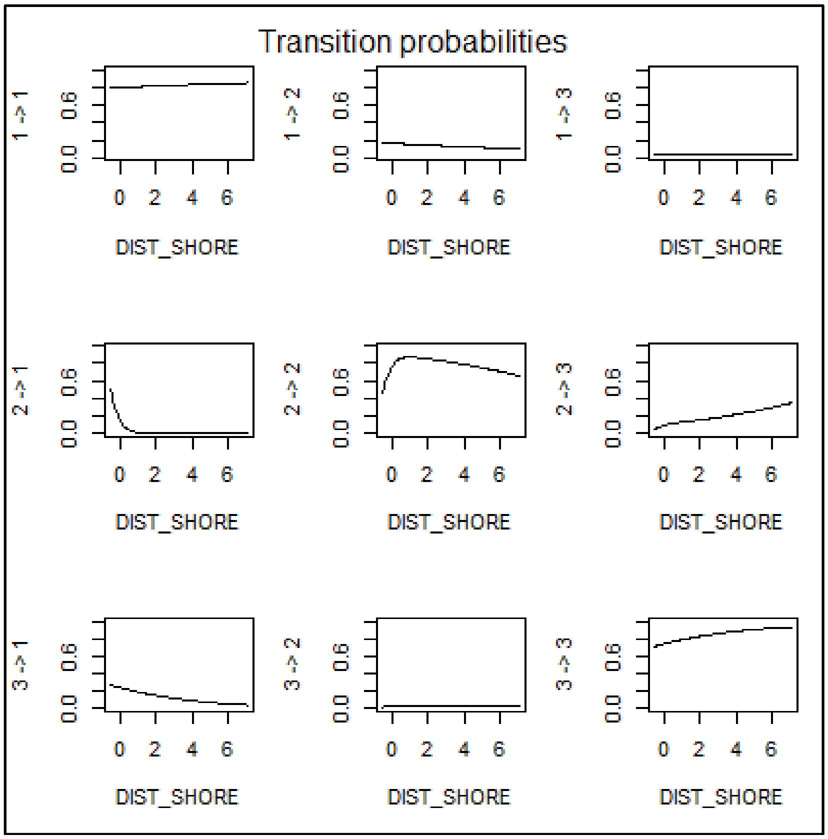

Figure B-3. Transition probabilities for the top model that included 'Distance from Shore'. The probability that birds would transition from Sedentary to Active (2 → 1) behavioral modes was negatively correlated to distance from shore, whereas the probability that a bird would remain in either 'Active' (1 →1) or 'Transiting' (3 → 3) behavioral modes increased with distance from shore. The shape of (2 → 2) likely reflects the tendency of birds to roost at ~1km distance from shore at night.

7. Synthesized Findings and Conclusions

7.1 Introduction

Marine birds employ varied, sometimes specialized and sometimes flexible, foraging and migratory behavior to exploit different dynamic ocean habitats (Schreiber and Burger 2001). As a result, avian interactions with anthropogenic marine activities and installations in the marine environment tend to be species-specific and related to habitat and oceanographic domains (Wiese et al. 2001, Wolfaardt et al. 2009, Ainley et al. 2015). For birds in the marine environment, the risk of adverse effects from offshore wind energy development is a function of their vulnerability, which is strongly influenced by the behavior and life history of each species, and specific aspects of the development itself, such as the scale and location of the development (Goodale & Milman 2016). In general, species are vulnerable to the effects of offshore wind development, based on intrinsic or innate behaviors that will increase exposure rates, such as feeding, breeding, or migrating behaviors (Goodale & Stenhouse 2016).

Exposure to offshore wind development has spatial and temporal components that need to be considered. Spatially, exposure is dependent on how a bird uses habitat within a particular area, including the altitude at which it flies. Temporally, bird exposure is dictated by a species' life history and annual cycle and may be limited to particular life stages when it uses an area (i.e., breeding, molting, migrating, or wintering). This study focused on three species of diving birds, identified as vulnerable to offshore wind development (Furness et al. 2013). Collectively, these species represent a cross-section of marine birds found throughout the region and the wider North Atlantic Ocean (Nisbet et al. 2013). We used satellite tracking technology to investigate how these species could be exposed to offshore wind development during migration and winter in the mid-Atlantic U.S., an area with the greatest potential for offshore wind development in the country (BOEM 2017).

Our study species were:

- Surf Scoter (*Melanitta perspicillata*), a nearshore invertivorous sea duck that feeds primarily on mollusks;
- Red-throated Loon (*Gavia stellata*), a small, piscivorous loon that winters in relatively sheltered marine waters;
- Northern Gannet (*Morus bassanus*), a nearshore to offshore piscivorous plunge-diver, and the largest seabird to breed in the North Atlantic.

This study provides new information on winter movements and habitat use of these species, which could be vulnerable to effects of offshore wind development in the mid-Atlantic region. Substantial proportions of the North American populations of these species exploit different marine habitats in the study area during the migration and wintering periods of their annual cycles (Nisbet et al. 2013), and each is considered to be of management and/or conservation concern in the U.S. (MANEM 2006, USFWS 2008a). The offshore waters of our study area are a complex ecosystem that exhibit highly variable temporal and geographic patterns, driven in part by the influence of the Gulf Stream to the east, and a series of large embayments to the west. Between 2012 and 2015, we tagged 239 gannets, loons, and scoters, each with its own unique relationship to the study area, and examined PTT data from a total of 386 individuals of the three focal species, making this one of the most comprehensive satellite tracking studies of marine birds conducted in Atlantic waters of North America. This information is an important step in understanding how and when these species, and potentially other species utilizing similar habitat, could be exposed to offshore wind development in the region. Study findings provide insights into risks of potential offshore wind development on diving birds in the study area that could be used to inform siting decisions. In addition, our findings contribute to a baseline understanding of how these species use the study area, prior to any offshore energy development, information that could be helpful in post-construction assessments.

In this synthesis chapter, we summarize commonalities and differences in winter use and migrations for three focal diving marine bird species, highlight persistent patterns and habitat associations, and compare results with other available knowledge for these species. We also highlight methodological considerations and examine how information obtained from our tracking analysis both differs from and complements information from survey data models in order to better understand the distribution and abundance of marine birds in our study area. Lastly, we discuss how our findings may inform the assessment of exposure and risk of our study species to development in federally-designated WEAs and Lease Areas in the mid-Atlantic, and suggest further work that may improve this understanding.

7.2 Methodological and Analytical Considerations

To model the potential cumulative impacts or risks associated with offshore wind energy development, accurate information is needed about the spatial and temporal distribution of vulnerable species, and the underlying factors driving distributions in an area. Species distribution models (SDMs) for marine birds are based upon data obtained through either offshore surveys (aerial, boat-based, or both) or telemetry studies (Clark et al. 2003, Yen et al. 2004, Louzao et al. 2009, Nur et al. 2011, Oppel et al. 2012, McGowan et al. 2013, Bradbury et al. 2014, Winiarski et al. 2014, Heinänen et al. 2017). Both survey and telemetry data can be used to predict the probability of presence or habitat suitability. However, estimating abundance requires careful consideration of the potential biases associated with each of these data collection methods.

7.2.1 Capture-based Telemetry

Telemetry provides data on an individual's movement patterns across space and time from the point of capture, but generally assumes tagged birds behave and move identically to untagged individuals. Efforts are made to avoid capture biases in the data, such as removing birds that may have died soon after surgery, or restricting analyses to birds that contributed a threshold number of tracking days to the dataset. We employed both of these methods in this study.

In addition, a sample of tagged individuals is often used to describe the distribution of a species, which assumes that the sample is representative of the population. Several aspects of this study (and others) present challenges to this assumption of unbiased sampling. For example, birds are often caught in areas that are most accessible (rather than where birds may preferentially congregate), and at specific times and in favorable conditions.

Furthermore, sample sizes are often limited by logistic and financial constraints; thus, the assumption that tagging data are unbiased is difficult to substantiate. Despite these issues, however, remote data collection via telemetry offers biologists the ability to observe how patterns of distribution change across space and time in response to weather, habitat availability, and season – continuously recording data after capture regardless of environmental conditions. No other method provides these kinds of data.

7.2.2 Technology considerations

This study used surgically implanted PTTs to collect hourly relocations of marine birds from 2011-2015. These transmitters performed extremely well during the study, with a < 2.4% failure rate observed. Each species' tolerance of tagging was individually assessed (see species chapters). A meta-analysis done on post-release mortality indicates that Red-throated Loons were the most susceptible to the stresses associated with capture, handling, and the surgical procedure, while Northern Gannets had a greater tolerance of the process overall. Capture and handling stress significantly influenced early survival of Red-throated Loons during our project, while for Northern Gannets, anesthetic duration was most critical (Chapter 5). Surf Scoter survival was not significantly related to any of the factors measured (Chapter 5). Overall, our results emphasize that survival could be improved with refinement or elimination of capture, handling, and the surgical procedures.

We attempted to address some of these factors by testing external solar-powered tags that avoid extended handling times, anesthesia, or the weight and volume costs of having a battery-powered implantable transmitter. Using GPS-GSM transmitters attached with harnesses (and additional deployment of tail-taped tags on Northern Gannets), we observed high mortality in Red-throated Loon and Surf Scoters, and immediate tag loss in Northern Gannets. Although this pilot study was largely unsuccessful, it highlighted specific improvements that could be made for future deployment of emerging technologies that require external attachment on marine birds, especially non-diving pelagic species that may be more tolerant of additional weight and drag caused by an externally-mounted tag (e.g. pelicans, gulls, petrels, etc.). We expect use of these technologies will become increasingly important to modeling fine-scale movements in response to weather and habitat covariates as birds navigate the offshore environment.

7.2.3 Comparing Brownian Bridge Models with Predictive Avian Survey Models

We overlaid the results of dynamic Brownian bridge movement models (dbbmm) from this study with predictive distribution and abundance models produced by the Marine-life Data and Analysis Team (MDAT) from avian survey data (Kinlan et al. 2016, Curtice et al. 2016). The MDAT's models were developed using offshore survey data spanning several decades (1978 - 20014) and collected using a variety of survey techniques within the U.S. Exclusive Economic Zone (EEZ) from Florida to Maine at a 2 x 2 km resolution beginning 1-2 km offshore. The MDAT's models do not cover the Bay of Fundy, Long Island Sound, Chesapeake Bay, Delaware Bay, and other inshore, nearshore, and estuarine areas, which limited comparisons in these areas, which were heavily utilized by our focal species. In general, there is agreement between the results of our dbbmm models and the MDAT's models in the distributions of all three species in winter (Figure 7-1). In contrast, however, there is less agreement between the models for the fall (Figure 7-2) and spring (Figure 7-3) migration periods. This mismatch between the models during migration is likely explained by a combination of spatial-temporal differences in the data, methodological differences, and ecological differences of the focal species.

Specifically, the seasonal partitioning and temporal resolution of data was notably different among methods, which in combination with the much longer time frame of the MDAT's model data was a likely driver of many of the incongruities. Additionally, geographic coverage of at-sea surveys was limited to those specific areas surveyed, rather than the global coverage provided by satellite tags. This affected the geographic scope of the MDAT's model predictions (e.g., minimal coverage of nearshore areas and bays). Alternatively, the survey data provided information on all animals in the area surveyed at a given time, and therefore was not subject to the small sample size bias of the telemetry data, which affects inferences that can be made to broader populations. In the future, combining these types of models would greatly improve our understanding of these species distribution and movement patterns (see 7.5.2.1 below).

7.2.4 Methodological Considerations for Data Analysis

Understanding the physical and biological habitat requirements of a species throughout their annual cycle is critical for effective wildlife management. The factors that influence the distribution of a species across the landscape, however, cannot be identified without first quantifying the space used by animals. Multiple methods exist to quantify space use, with most focused on estimating a probabilistic model of an animal's home range – called the utilization distribution (UD; Worton 1989).

Kernel density estimation is a standard method used to examine the variation in intensity of spatial point patterns and can be applied to location data obtained from satellite transmitters. This method makes no assumption about the underlying distribution, and assumes independence of observations for an unbiased estimate (Worton 1987). Animal location data is inherently autocorrelated in both space and time due to the non-random movement of animals, which makes kernel estimate applications prone to higher amounts of mean integrated squared error (MISE). Commonly suggested procedures for dealing with this include: subsampling; removing data to increase time and distance between observations; and stratification across individuals (Swihart & Slade 1985, Otis & White 1999). Autocorrelation indicates a relationship between one point in time and those that occurred before and after it, and, by removing that relationship from the data using the above techniques, one also reduces sample size and the ecological significance of the analysis (De Solla et al. 1999).

Alternatively, the dynamic Brownian bridge movement model works by incorporating the temporal structure of tracking data to estimate the utilization distribution along an animal's movement path (Kranstauber et al. 2012). It uses a Brownian motion variance parameter to measure how straight or irregular a movement path is between successive points to create more accurate UD estimates compared to other methods (Kranstauber et al. 2012, Byrne et al. 2014). We ultimately chose this method to model UDs during the winter and migration periods for each of our focal species for the following reasons: (1) it accounted for spatial and temporal autocorrelation without necessitating subsampling or coarsening of the data set; (2) robustness to irregular sampling schedules associated with the duty cycles of the transmitters, and (3) it incorporated location error estimates, which allowed us to include data points with lower quality location classes that would have been omitted using other methods. Overall, this approach used a larger proportion of the data collected for each species and produced more conservative, and, hopefully, realistic predictions of the UD for the animals in our study, compared to kernel methods.

7.3 Use of the Study Area

7.3.1 Timing of Species' Movements

During the fall (southerly) migration, satellite-tagged individuals began arriving in the Mid-Atlantic study area in early October. Northern Gannets were the first species to arrive, followed soon thereafter by Surf Scoters. Red-throated Loons began arriving in the area in November. All three species were present in the study area throughout the winter. The majority of individuals departed the study area on their spring (northerly) migration in April–May (Figure 7-4).

The first Northern Gannets arrived in the study area in early October, with females generally arriving just a day or two ahead of males. Birds from colonies in the Gulf of St. Lawrence arrived slightly earlier than birds from Newfoundland colonies. Individuals continued to arrive in the study area from early October (10 October) to mid-November (14 November).

Differences in the timing of arrival among species are likely associated with their breeding proximity. Northern Gannets, for example, are the closest breeders, with colonies in southeastern Canada. Surf Scoters breed at higher latitudes and have a shorter nesting period than Northern Gannets, but spend considerable time at stopover areas along their migratory routes, such as Hudson Bay, James Bay, and the St. Lawrence River. They then continue moving south to the Mid-Atlantic, resulting in a slightly later arrival. Our tagged Red-throated Loons generally nested at very high latitudes and have a relatively long nesting period. They also spend a long period, presumably molting, in Hudson Bay and James Bay. Consequently, our Red-throated Loons arrived in the Mid-Atlantic study area considerably later than the other species.

Despite the staggered arrival of the focal species, there was a long period of overlap when all three were present in and around the study area over the winter months. Most of the satellite-tagged birds in the study were entirely present in the study area from early November to mid-April. Only individual Northern Gannets strayed outside of the study area for any length of time, as is evidenced by dips in the proportions of animals present. Northern Gannets are also the most wide-ranging of the species, so it is not surprising to find that they were not all present in the study area through the entire winter period. A few Northern Gannets spent most or all of the winter in the Gulf of Mexico, rather than the Mid-Atlantic, as is typical of the species.

During spring, Northern Gannets moved out of the study area by the first part of May, while a few Red-throated Loons lingered until late May. Surf Scoters remained in the study area the longest, with the last individuals departing in mid-June.

As is the case for many migratory species, the departures of all three focal species were generally more compressed in time and more directed than arrivals (Figure 7-5). By March, Northern Gannets were beginning to work their way northward through the study area. Aggregations built up around the mouth of Chesapeake Bay reliably in mid-March before moving northward through Delaware Bay and the New York/New Jersey Bight. Departures began in earnest by mid-April. With males departing a week earlier than females, Northern Gannets moved directly back towards breeding colonies. In contrast, Surf Scoters and Red-throated Loons typically spent some time staging, often in similar areas. These species showed heavy use of the Nantucket Shoals, areas adjacent to Prince Edward Island, and the St. Lawrence River, before continuing migration to northern nesting locations.

7.3.2 Winter Habitat Selection and Important Habitat Characteristics

All three study species made extensive use of the large bays on the eastern U.S. coast. Surf Scoters utilized near shore and bay habitats and exhibited very little overlap with WEAs during winter. Winter use of the study area by Red-throated Loons was also most concentrated within the large bays of the Mid-Atlantic study area—Delaware Bay, Chesapeake Bay, and Pamlico Sound. The wintering core use areas of Northern Gannets also included Delaware Bay, Chesapeake Bay, and Pamlico Sound. These large bays are highly dynamic areas of immense productivity, and important areas for shellfish production and reproduction and growth of marine fish (Correll 1978, Roman et al. 2005). Wintering gannets also used U.S. Atlantic shelf waters widely, which was reflected in the degree of their overlap with WEAs and Lease Areas.

Northern Gannets are opportunistic foragers that target small to mid-sized surface-schooling fishes in dramatic plunging dives, as well as diving directly from the surface (Garthe et al. 2000, Montevecchi 2007). Red-throated Loons are pursuit divers that dive from the surface to pursue their small forage fish prey (Eriksson 1985, Guse et al. 2009). Surf Scoters are benthic feeders that forage primarily on a variety of clams and mussels on their wintering grounds (Baldassarre 2014).

Our resource selection analysis results indicated that core use areas for all three species were associated with shallower, colder, and more productive waters, compared to other locations within each of their winter home ranges. Yet, we noted differences in the range of values associated with the habitat characteristics we measured within the winter core use and home range areas of each species. All three species exhibited a coastal distribution and concentrated use in the large bays of the study area. Differences in prey, however, presumably led to the variation in space use we observed among the three species. For example, Northern Gannets are highly mobile predators and their use of the study area ranged much farther offshore, compared to Red-throated Loons and Surf Scoters, extending out to 122 km offshore for core use areas and 150 km for home ranges. In contrast, the core use areas and winter home ranges of Surf Scoters only extended 25 km and 54 km from shore, respectively, and only 23 km and 47 km from shore for Red-throated Loons. Associated with distance from shore, variations in water depth of core use and home range areas showed similar patterns among the three species. Seventy-five percent of locations in Northern Gannet core use areas were in water depths of less than 20 m, whereas the same proportion of points in Red-throated Loon core use areas were in water depths less than 15 m, and less than 10 m for Surf Scoter core use areas. In addition, although distance from shore and water depths ranged considerably among the species, half of all locations in core use areas of all three species were within waters with long-term mean winter sea surface temperatures of 4–6 °C.

Higher levels of chlorophyll a were also associated with higher probabilities of core use area selection among all three species; however, chlorophyll a concentrations within Surf Scoter core use areas were almost twice as high as Northern Gannet and Red-throated Loon core use areas. Increased chlorophyll a is associated with increased primary productivity, which, in turn, can be associated with higher biomass production of pelagic forage fish, but, it can also be associated with decreased water clarity at elevated levels (Kemp et al. 2005). Northern Gannets and Red-throated Loons are visual predators that rely on light to pursue prey, and, turbidity may be a limiting factor associated with foraging in waters with very high chlorophyll a concentrations. Specifically, Ainley (1977) proposed that plunge divers require relatively clear waters to maintain a visual fix on prey, whereas pursuit divers may benefit from some degree of water turbidity if it provides cover when approaching prey. Foraging efficiency of Surf Scoters, keying in on sedentary food resources, may be less constrained by water clarity. Although that argument is admittedly confounded by the assumption that areas where they forage would presumably benefit from water filtration processes associated with oyster reefs, resulting in reduced plankton biomass and increased water clarity. Nevertheless, the ability to forage in some degree of turbidity is likely what has allowed Red-throated Loons and Surf Scoters to exploit tidal rivers to the extent they have within the study area. Salinity coverage at Surf Scoter locations was insufficient to include in resource selection models; however, lower seasonal sea surface salinity was associated with greater probability of core use area selection among the Red-throated Loons we tracked. These rivers outflows, particularly during periods of peak discharge in spring, can influence salinities, stratification, and circulation in marine waters (Whitney 2010). Such salinity fronts, and the thermal fronts with which they are associated, found at the mouths of rivers and bays and oceanic shelf breaks, create an upwelling of nutrients that attract forage fish to surface waters and enhance foraging opportunities for marine birds (Haney & McGillivary 1985).

Food availability is presumably the most important constraint affecting habitat use during the nonbreeding season (Hutto 1985), but, direct correlation between marine bird and prey distributions is constrained by the hierarchical patch structure of prey, such as pelagic schooling fish and crustaceans (Fauchald 2006). Hierarchical patch structure is based on the idea that a patch at a given scale is comprised of finer-scale patches, all of which are nested within a mosaic of broader-scale patches and the responses of organisms to heterogeneity in habitat are not confined to just one level (Kotliar and Wiens 1990). Indeed, marine bird abundance typically shows greater spatial correlation with prey abundance at larger scales (> 100 km) compared to smaller scales (< 10 km; as reviewed by Scott et al. 2013). Therefore, physical oceanographic processes, such as fronts, are more likely to be reliable predictors of prey availability and abundance for piscivores, compared to biological phenomena, such as the timing of fish migrations and spawning (Schreiber and Burger 2001).

7.3.3 Overlap in Species Distributions and Persistent Hotspots

All three species showed consistent use of coastal waters of the study area and the mouths of large bays, such as Delaware Bay and Chesapeake Bay. Heavy use of protected waters, such as Pamlico Sound and upper and middle Chesapeake Bay, as well as lower sections of large tributaries was also observed among Northern Gannets, Red-throated Loons, and Surf Scoters. The preference for shallower waters exhibited by Red-throated Loons and Surf Scoters likely contributed to a greater overlap in habitat use among these species. Interestingly, the fish prey of Red-throated Loons is likely much more mobile, compared with sedentary nature of the benthic prey of Surf Scoters, suggesting that the overlap only occurs when prey resources are aligned and when birds are in transit or resting in similar areas. Northern Gannets overlapped less often with Surf Scoters and Red-throated Loons, occurring in high concentrations within Delaware Bay and Chesapeake Bay in early spring when the other species were generally leaving for spring migration. In fact, Northern Gannets were less prevalent earlier in winter when Red-throated Loons and Surf Scoters were more reliably found in those areas. In general, Northern Gannets used offshore coastal waters of the Outer Banks more consistently throughout winter, compared with other regions of the study area. They also used Pamlico Sound consistently throughout the winter, similar to Red-throated Loons and Surf Scoters, but not in as large numbers. Goyert et al. (2016) found that Delaware Bay and Chesapeake Bay were associated with high abundance estimates of marine bird species across multiple seasons, including Northern Gannets, loons, and scoters, as well as auks (Razorbills), terns, and gulls.

7.4 Broader Migratory Patterns

7.4.1 Spring Migration

Not surprisingly, given their extensive northern breeding ranges, some similar patterns of migration exist between Red-throated Loons and Surf Scoters. Spring migration is particularly similar between these species which move north along the coast, stopping at several important staging areas along the way, including Nantucket Shoals, Prince Edward Island, and the St. Lawrence River. The Nantucket Shoals appear to be a particularly important migratory stopover site, with all three of our focal species visiting for some length of time. The Nantucket Shoals have been shown to be an incredibly rich feeding area, due to the persistent oceanographic fronts that set up on the western edge of the shoals (White et al. 2009). These fronts concentrate plankton and fish prey, resulting in massive flocks of birds over the shoals, particularly along the western boundary. This area was identified during recent surveys as a hotspot for Long-tailed Ducks, White-winged Scoters, Northern Gannets, and Razorbills (Veit et al. 2016).

Surf Scoters followed a route within 18.5 km of the Atlantic coastline to staging areas near the Gulf of St. Lawrence. As such, Surf Scoters overlapped with WEAs from coastal New Jersey to coastal Massachusetts during migration. Little overlap was found further south. Although Surf Scoters are not likely to be as heavily impacted by wind facilities offshore as other marine bird species, concurrent near shore state-managed leases (< 5.6 km) may directly impact Surf Scoters through mortality and/or through the alteration of available forage habitat.

As with Surf Scoters, most Red-throated Loons moved coastally through the Gulf of Maine into the Gulf of St. Lawrence and then in a more broad front migration overland to their northern breeding grounds. A small number of both species, however, moved to the Great Lakes to stage and then continued on to breeding areas mostly to the northwest. These routes clearly provide the shortest overland distance and the benefit of food and rest along the long flights to remote breeding areas.

Northern Gannets also migrate coastally in the spring, moving broadly north across the OCS, likely resting and feeding along the way. For short periods, numbers build up at a few important sites, including the mouth of the Chesapeake Bay, Delaware Bay, and the New York/New Jersey Bight. Some Northern Gannets also staged briefly on offshore banks off of Nova Scotia, the Banquereau and the Saint Pierre Banks, probably exploiting consistent prey resources such as herring (*Clupea harengus*; Soldat 1976) or capelin (*Mallotus villosus*). Northern Gannets also use areas around Prince Edward Island and the St. Lawrence River, suggesting that these are rich feeding areas, but also in close proximity to the major breeding colony on Bonaventure Island. The St. Lawrence River is a very large estuarine system and has similar hydrographic features that concentrate prey as the bays in the Mid-Atlantic, including tidal fronts, convergence zones, and hydraulic controls at various points along the extent of the tidal portion of the river (El-Sabh & Silverberg 1990).

7.4.2 Fall Migration

Fall migration appears to be more leisurely among all three species, which feature staging for post-breeding molting and foraging. As with spring migration, large estuarine systems play a key role in the ecology of these species. Surf Scoters and Red-throated Loons show heavy use of Hudson Bay and James Bay immediately after breeding. During their post-breeding molt, Red-throated Loons linger in southern Hudson Bay for up to two months, probably using the strong coastal current that exists there (Wang et al. 1994) to carry them south into James Bay. Most Surf Scoters and Red-throated Loons visit the St. Lawrence River estuary on their return for various lengths of time, from weeks to a month or more, again highlighting the richness of this ecosystem and its geographic importance to these species. Final return to the Mid-Atlantic is either overland directly or coastally. A small proportion of Red-throated Loons also visit the Great Lakes on their southern migration. To a lesser degree, both species pause on the Nantucket Shoals before reaching wintering grounds in the Mid-Atlantic.

Northern Gannets follow a much more coastal route on their return to the wintering grounds, mostly hugging the coast. A few strayed well offshore to outer banks or sea mounts, presumably following prey resources or other cues, such as fishing vessels.

7.5 Conclusions

7.5.1 Exposure and Vulnerability

Our results clearly show that each of the three species tracked has different occupancy patterns within the WEAs (see Tables 2-3, 2-4 for Northern Gannets, 3-2 and 3-3 for Red-throated Loons, and 4-3 and 4-4 for Surf Scoters). Our results indicate that Northern Gannets would be exposed at the highest rate if offshore wind facilities were constructed in existing WEAs and Lease Areas, followed by Red-throated Loons, and then Surf Scoters. WEAs and Lease Areas overlapped extensively with Northern Gannet distributions during both migrations and winter. The broad exposure of the Northern Gannet is to be expected since they feed upon highly mobile forage fish, such as Atlantic menhaden (*Brevoortia tyrannus*). In contrast, Red-throated Loons will primarily be exposed to WEAs north of North Carolina during spring migration, because in winter they are concentrated closer to shore and within large embayments. Similarly, Surf Scoters will be exposed most during spring migration in WEAs north of New Jersey, because, like Red-throated Loons, they are concentrated along the coast in winter. Despite potential exposure across the Atlantic OCS, our models suggest that such exposure makes up a very small proportion of a species' seasonal distribution (< 5% for gannets, which overlap WEAs more than the other two species).

Interpreting how these seabird exposure patterns will lead to adverse effects from offshore wind energy development patterns is challenging. Occupancy patterns within WEAs are a basic measure of potential exposure, but exposure is only one component of adverse effects (defined as a process of vulnerable species being exposed to the hazard of offshore wind development; Goodale and Milman 2016). Thus, in order to interpret how exposure may lead to adverse effects, we must also consider how vulnerable each species is to offshore wind energy development. Studies in Europe indicate that all three of these species are vulnerable to displacement, since they all largely avoid offshore wind facilities.

Although our results indicate that Northern Gannets could be exposed to offshore wind facilities in winter and migratory periods if they are developed in current WEAs and Lease Areas, studies in Europe suggest that Northern Gannets are most likely to avoid offshore wind turbines, resulting in a low risk of collision. Northern Gannets are considered by some researchers to be vulnerable to collision risk primarily because of the proportion of time they fly within the rotor swept zone (16%; Furness et al. 2013, Garthe et al. 2014, Cleasby et al. 2015). Yet, empirical evidence suggests that Northern Gannets avoid offshore wind facilities (Hartman et al. 2012, Garthe et al. 2017). Northern Gannets have been documented to have 64–84% macro avoidance rate and an overall 99.1% total avoidance rate (Krijgsveld et al. 2011, Cook et al. 2012, Vanermen et al. 2015). At the Egmond aan Zee in the Netherlands, 3% of Northern Gannets were seen flying within the wind development itself, 14% on the edge, and 83% outside (Krijgsveld et al. 2011). Habitat loss due to existing and proposed offshore wind developments in Europe is estimated to be 1.82% (Busch et al. 2013). If a bird were to enter the wind development, models estimate that the proportion of birds at risk height is 0.07 (Johnston et al. 2014).

Like Northern Gannets, Red-throated Loons are identified as a species vulnerable to displacement from offshore wind development (Furness et al. 2013). Pre- and post-construction monitoring, however, has demonstrated that Red-throated Loons consistently avoid projects after they are built and do not habituate to the development (Percival 2010, Lindeboom et al. 2011). Models of the cumulative effects of alternate development patterns suggest displacement can cause a 0.1–1.7% decrease in populations (Topping and Petersen 2011, Leonhard et al. 2013) and existing and proposed offshore wind developments could lead to an estimate 5.4% loss of habitat (Busch et al. 2013). Even if a bird were to enter a wind development area, models estimate that the proportion of birds at risk height is only 0.01 (Johnston et al. 2014).

While few data are available on the response of Surf Scoters to offshore wind developments, scoters in general, along with most sea ducks, are considered vulnerable to displacement (Furness et al. 2013). Prior research has suggested that Black Scoters may be exposed to offshore wind development close to shore during winter and offshore during migration (Loring et al. 2014). In Europe, avoidance has been documented for Common Scoter, Common Eider (*Somateria mollissima*, Lindeboom et al. 2011), Tufted Duck (*Aythya fuligula*), Common Pochard (*Aythya ferina*), and Greater Scaup (*Aythya marila*; Dirksen and van der Winden 1998 *in* Langston 2013). Avoidance of a single offshore facility by sea ducks is not considered to substantially increase energy expenditure (Masden et al. 2009). Collision risk of sea ducks is thought to be relatively low. Models of Common Scoters entering a wind development area in Europe have estimated that the proportion at risk height is 0.001 (Johnston et al. 2014).

Many of the studies referenced here that documented avoidance were conducted on the first European offshore wind developments, which used relatively small turbines (e.g., 2.3 MW). New projects being proposed in the U.S. and Europe include 5 - 6 MW turbines and some projects are even considering turbines as large as 8 MW (4C Offshore 2016). As wind turbines become larger, greater and greater spacing between turbines will be necessary, expanding project footprints and increasing the distance between turbines to 1.5 km or more. Such an increase in spacing may change marine bird avoidance responses, and may either continue to cause the birds to avoid the wind development or provide movement corridors through it. Thus, interpreting how the exposure patterns of all three species identified in our study will lead to displacement, and potential loss of foraging and wintering habitat, is unclear. Birds that are displaced by offshore wind farms may move to different areas with no consequence, or the displacement could have an indirect effect of reduced fitness, survivorship, and reproductive success

(Langston 2013). Thus, substantial questions remain on what effect the displacement will have to individual fitness and ultimately to populations.

7.5.2 Additional Information Needs

7.5.2.1 Integrate Multiple Data Types Into A Single Analytical Framework

Within the last decade, numerous marine bird surveys (USFWS 2008a, NJDEP 2010, Paton et al. 2010, Williams et al. 2015, Veit and Perkins 2014, NOAA 2015, Veit et al. 2015, 2016) and tracking efforts (SDJV 2014; Hatch et al. 2016, Loring et al. 2014, Loring et al. 2017a, b; this study) have produced a substantial amount of new information about bird abundance, distribution, and use of Federal waters of the U.S. Atlantic. Models from tracking and survey data can provide complementary information for better understanding abundance, distribution, and use at multiple spatial and temporal scales. Our comparison of the MDAT's survey data model and our dbbmm tracking data models was limited to a qualitative examination, by overlaying map layers of model outputs on top of one another (see section 7.2.5 above). While mapping tools exist for making similar qualitative comparisons using other datasets (*see* Northeast Ocean Data Portal, http://www.northeastoceandata.org /data-explorer/?birds; Kinlan et al. 2016), we know of no analytical methodologies that can be used to quantitatively model data provided by both survey and tracking information (Rob Fowler, USFWS, pers. comm.). Other studies have recognized the importance of integrating multiple types of data into a single analytical framework in order to inform a greater understanding of animal population dynamics and related conservation decisions (Williams et al. 2015, Zipkin et al. 2017). Biologists and statisticians need to work together more to create a novel framework for analyzing survey and tracking data available for marine birds in Atlantic waters. This information could be used to make more defensible management decisions related to offshore energy development and additional marine spatial planning needs.

7.5.2.2 Improve and Expand Use of New Tracking Technologies

The continuing evolution of tracking technology has the potential to revolutionize our understanding of animal movement and behavior, providing increasingly high quality data. The use of new lightweight solar-powered GPS-GSM transmitters could provide continuous and precise data that allow for sophisticated analyses that require time-invariant sampling and relocations with low error. However, these tags require external mounting with harnesses. While researchers have tracked raptors with great success using Teflon-coated ribbon harnesses, the deployment of similarly styled harnesses on diving marine birds has been largely unsuccessful, presumably due to the tag's interference with foraging behaviors (i.e. pursuit and plunge diving) by means of loss of waterproofing, balance, hydrodynamic influences, and poor harness fit during migration when birds experience rapid body mass changes. Our designs have proven successful for short-term deployment, although long-term success has yet to be determined. While this pilot work has shown promising analytical results, it highlights the need to empirically evaluate the effect of tag placement, design, and fit for diving birds, and further improve attachment design to maximize retention times while minimizing adverse effects on study species. This project highlighted that there is a complex interaction between tag attachment and transmitter design that likely impacts the ability of marine birds to forage or maintain waterproofing in the marine environment.

If transmitters adversely affect plumage integrity over time, or transmitters are susceptible to icing in winter conditions, reduced fitness and/or mortality may occur weeks or months after tags are first deployed. Hydrodynamic properties of tags and tag placement (drag and buoyancy) should be tested through a mixture of simulated modeling and behavioral observations on captive seabirds. This is highly relevant for diving birds as the body cavity and feather mass naturally compress during diving, reducing volume, while hermetically-sealed transmitters do not.

While improvements in tag placement and attachment are needed, an overall reduction in tag size and weight will reduce drag, as well as expand the suite of species that can be tracked. Use of the new ICARUS tags or VHF tags on the MOTUS wildlife tracking network (Loring 2016) could help to achieve these goals. ICARUS satellite tags will weigh < 5 grams and, in average solar conditions, obtain 12 GPS points per day, as well as 3D-acceleration, 3D-magnetometer, and temperature data (Wikelski et al. 2007) Beyond satellite or GPS tracking, there are also efforts underway to coordinate digital VHF (very high frequency) on a shared frequency (e.g., the MOTUS Wildlife Tracking System), allowing for thousands of tagged animals to be detected on an expanding network of receiving stations throughout North and South America (Loring 2016). At present, however, satellite-based technology is the primary option for large geographic scale wildlife tracking throughout an animal’s life cycle, especially species that spend much of their lives at sea (Loring 2016).

New tracking technology could also assist with better understanding risk at future wind development sites. Offshore wind facilities present particularly unique challenges in predicting and quantifying either potential or observed conflict between the proposed facilities and birds. Accurate data on spatial, temporal, and activity-specific variability in flight heights that put marine birds at greater risk of adverse impacts are lacking (Johnston et al. 2014). Flight heights of birds have largely been estimated during ship-based surveys involving surveyors’ subjective assessment by eye, the accuracy of which remains unquantified (Cook et al. 2012; Johnston et al. 2014). While radar can quantify flight heights and tracks much more accurately (Desholm et al. 2006), there are limitations in spatial extent (maximum range typically 6 km from source), cost, and species determination. In the near future, GPS-GSM tags will be able to provide precise altitudinal data. Furthermore, these tags will also have accelerometers that can indicate plunge-diving events and behaviors, such as roosting, soaring, and active wing-flapping, which can been used to calculate energetic expenditure (Amélineau et al. 2014). These data could be used to improve collision risk models for marine birds migrating through the proposed wind energy areas by providing data on movement parameters (speed, direction) and determine the influence of demographic (age, sex), atmospheric (wind speed, wind direction, barometric pressure, atmospheric and sea-surface temperature, precipitation, visibility), and temporal (time of day, season) covariates on the exposure of marine birds to potential offshore wind facilities use, which is a logical research need.

7.5.2.3 Use Tracking Data as Baseline Pre-construction Information

A common approach used to assess how marine birds will respond to offshore wind energy development is to conduct pre- and post-construction monitoring, yet this approach rarely has enough statistical power to detect change (Maclean et al. 2013). The distribution and abundance of marine birds are affected by inter- and intra-annual variation in environmental factors (e.g., primary productivity, prey, and weather). Environmental conditions during surveys can substantially affect estimates of abundance (Lapena et al. 2011). In order to detect bird displacement from a project, traditional boat and aerial surveys must be conducted frequently over a larger area. Often conducting surveys of this breadth is beyond the scope of project specific permitting requirements, logistically challenging, and costly.

Individual tracking of marine birds, using satellite telemetry, complements traditional survey methods. Tracking data can be used to estimate UDs, analyze habitat relationships, identify persistent concentration areas, identify migratory routes, and provide detailed information of diel movement patterns. Each of these analyses provide detailed information of how birds use marine habitats and have the potential to assess how birds respond to offshore wind developments. Satellite tracking is now being used in Europe to examine how Northern Gannets respond to wind facilities, and preliminary results suggest they exhibit strong avoidance behaviors (Garthe et al. 2017).

Using satellite telemetry, our research has taken the first step in developing a regional baseline dataset on three species of potentially vulnerable marine birds prior to the development of any offshore wind farms on the Atlantic OCS. While pre-construction avian monitoring at commercial wind farms traditionally uses boat and aerial surveys, individual tracking data should also be considered as a viable method to assess how birds respond to a project. Ideally, birds could be captured and fitted with satellite transmitters as close to a development site as possible in the year prior to development, during construction, and once the wind farm is operational (years 1, 3, 5). These data could provide substantial insight into how birds respond to the project in real time, and, ideally, if conducted multiple years after a project is operational, how the response changes as a benthic community is established around the base of the turbines. In addition, since telemetry projects are able to track wintering birds from a project site through migration to the breeding grounds, telemetry data will provide data on (a) the population of birds being exposed to a specific project, and (b) how individual birds will be cumulatively exposed to other existing and proposed offshore wind projects. Combined, these data would be the first step in evaluating potential cumulative effects of multiple offshore wind facilities on marine bird populations.

7.5.2.4 Better Link Marine Bird Movements with Distribution and Behavior of Prey

The conservation and management of marine systems requires an understanding of the dynamics of predator-prey relationships that occur across a multitude of scales within the offshore environment. The identification of key marine habitats for marine birds, however, is constrained by the inherent spatial and temporal variability of their prey distributions, such as pelagic schooling fish (Fauchald 2000). The end result is a hierarchical patch structure where prey are clustered in fine-scale high-density patches, which are nested within a mosaic of broader-scale low-density patches, and the responses of predators to such heterogeneity in their habitat are not confined to just one level (Kotliar and Wiens 1990). Highly-mobile marine predators behave opportunistically and utilize a variety of strategies to achieve optimal foraging success. Thiebault et al. (2014a) suggested that breeding Cape Gannets (*Morus capensis*) increased foraging efficiency of patchily distributed prey by relying upon a network of conspecifics as cues to locate ephemeral resources. Large aggregations of conspecifics (100 - 150 individuals) elicited responses from individuals up to 40 km away that changes their flight trajectory to join the group (Thiebault 2014b). It is uncertain, however, whether such information flow can be relied upon during the non-breeding season when individuals are not constrained by foraging distance from the colony. Data focused on foraging movements of marine birds in winter is limited and quantifying the spatio-temporal overlap of predator-prey distributions throughout the annual cycle is a much-needed area of research with important implications for management of seabird and fisheries populations. Marine birds appear to forage where prey is most consistently available and not necessarily where it is most abundant (Ainley et al. 2009, Montevecchi et al. 2009, Pettex et al. 2010). Weimerskirch (2007) found that the availability of patchy resources were fairly predictable at large (> 1000 km) and meso-scales (100–1000 km), but, were much less so at coarse (1–100 km) and fine (< 1 km) scales. Heterogeneity in prey distributions and abundance likely occurs as a consequence of both behavioral factors (e.g., shoaling/swarming) and responses to physical forcing processes (e.g., currents and fronts; Santora et al. 2014). Physical processes, such as shelf edges, fronts, and upwelling zones, presumably produce conditions that aggregate or attract prey and/or make them available more consistently over time and at smaller scales compared to biological phenomena (Shealer 2002).

Understanding the physical processes and trophic transfer that occurs within these zones is an area of current research that merits greater attention and support. Furthermore, quantifying the variability of predator responses to these areas within and between seasons, species, and habitats would provide vital information for marine bird and fisheries management, and marine spatial planning. Studies that combine both large-scale vessel-based surveys and fine-scale GPS tracking data hold the greatest potential for identifying distribution patterns and key supporting oceanographic habitat characteristics. Vessel-based surveys provide population-level information regarding predictable hot-spots of predator-prey aggregations across large areas, while tracking data provide detailed information on the use of specific habitats by individual foragers (Louzao et al. 2009). The collation of data from multiple sources can then be used to develop species distribution models that identify influential oceanographic variables, which can be used to predict habitat use outside of the survey area, and aide in the identification of priority conservation areas at a wider scale (Lavers et al. 2014).

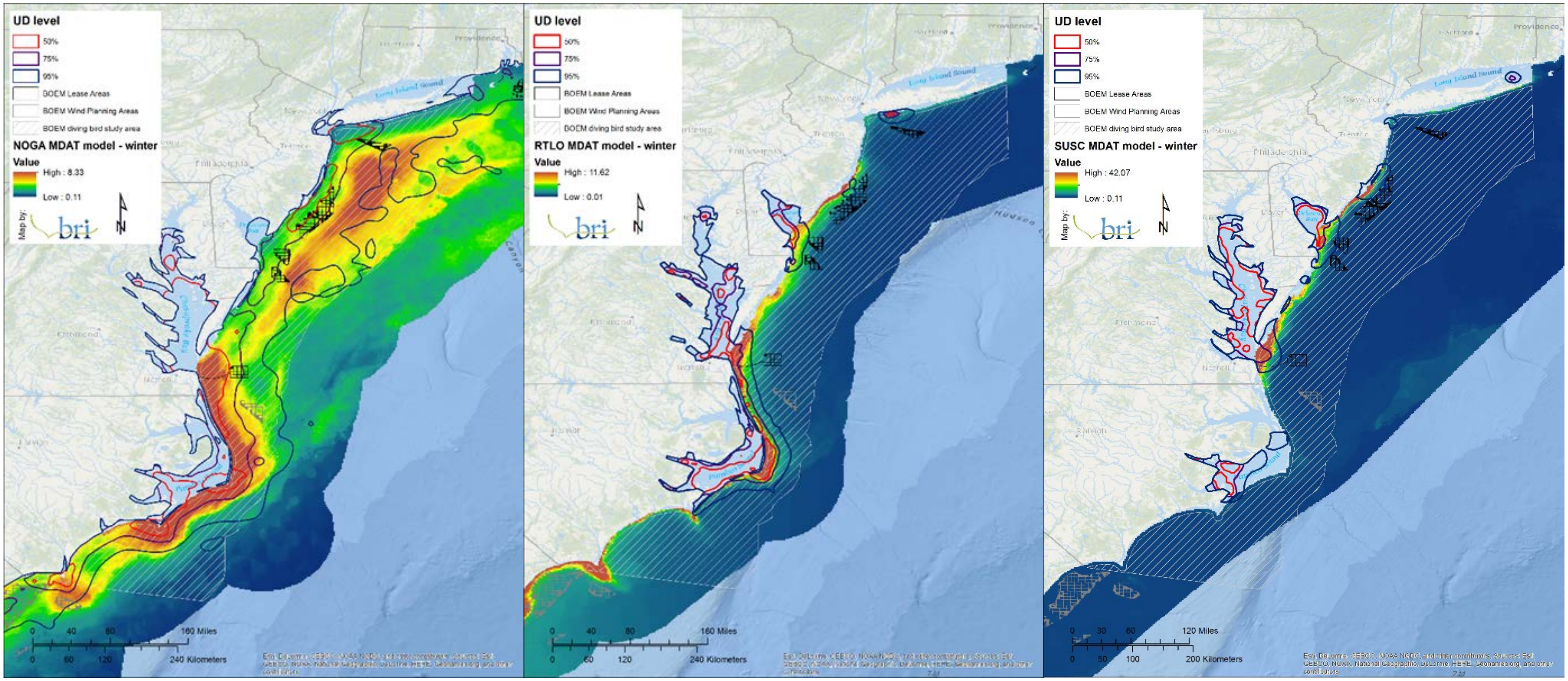

Figure 7-1. Comparison of Brownian bridge movement models for adult Northern Gannets (left), Red-throated Loons (center), and Surf Scoters (right) to predictive avian abundance and distribution models produced from survey data by the MDAT during winter.

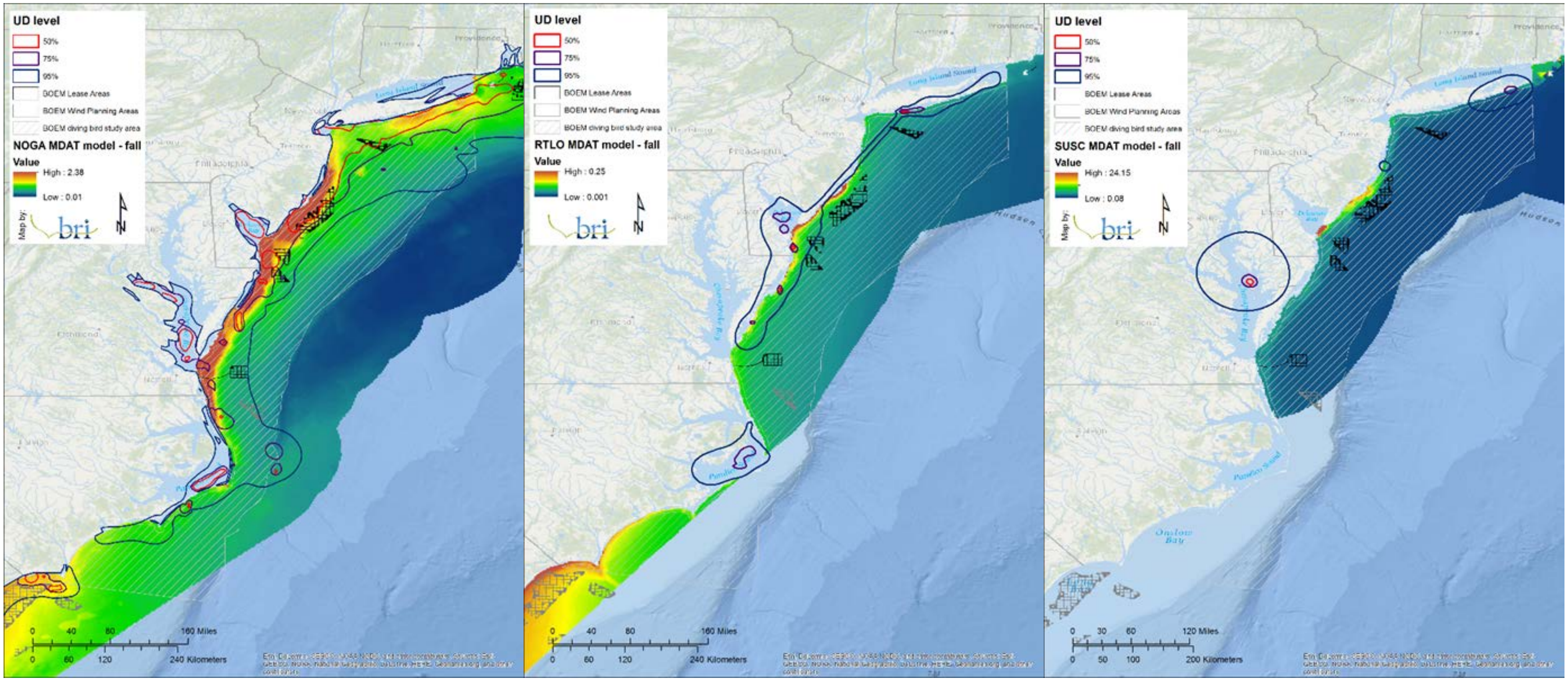

Figure 7-2. Comparison of Brownian bridge movement models for adult Northern Gannets (left), Red-throated Loons (center), and Surf Scoters (right) to predictive avian abundance and distribution models produced from survey data by the MDAT during fall.

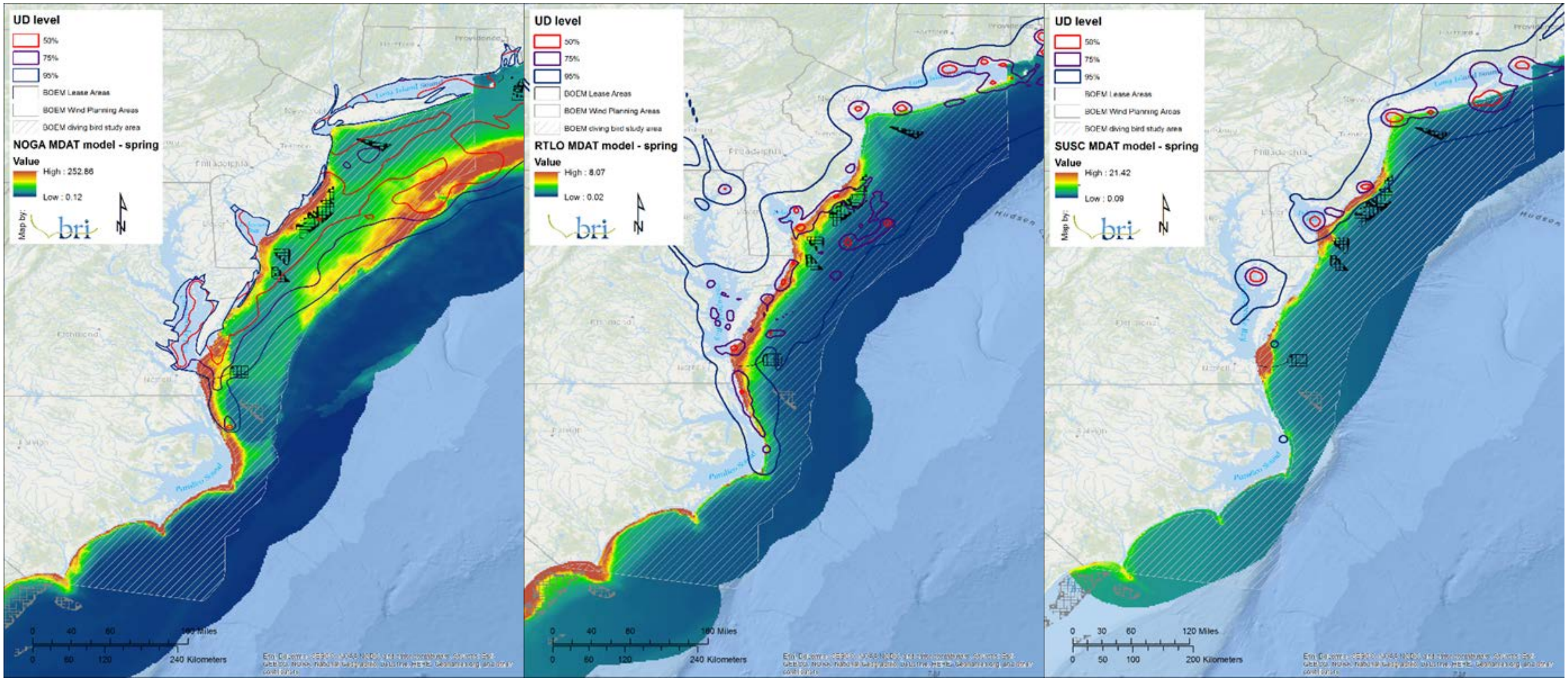

Figure 7-3. Comparison of Brownian bridge movement models for adult Northern Gannets (left), Red-throated Loons (center), and Surf Scoters (right) to predictive avian abundance and distribution models produced from survey data by the MDAT during spring.

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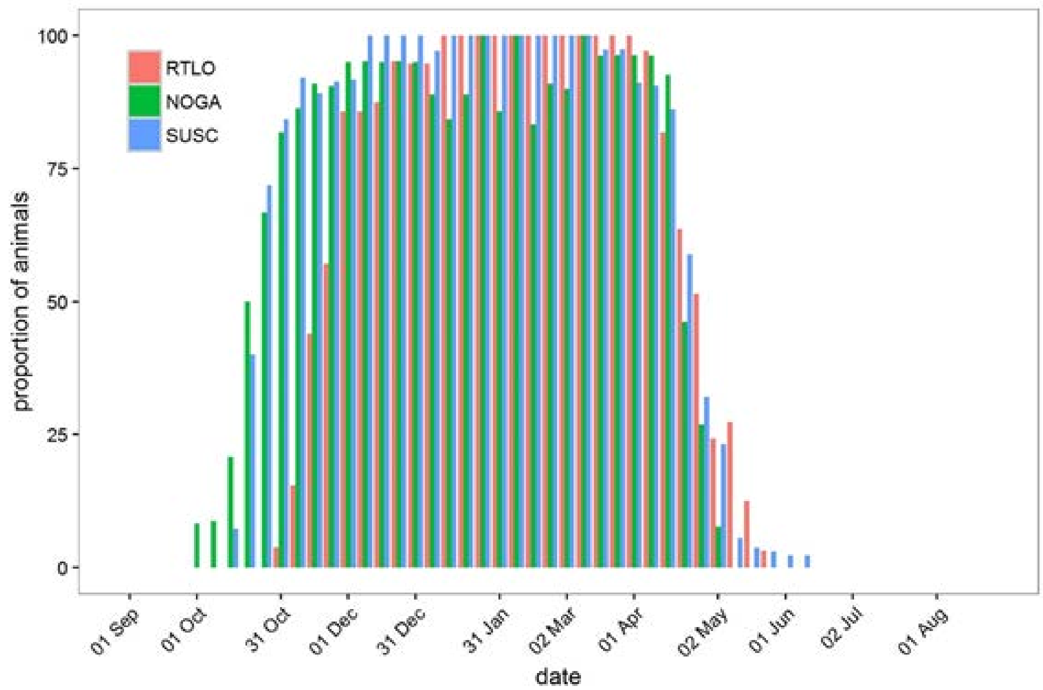

Figure 7-4. Timing of use of the mid-Atlantic study area for adults of all three species (2012 - 2015).

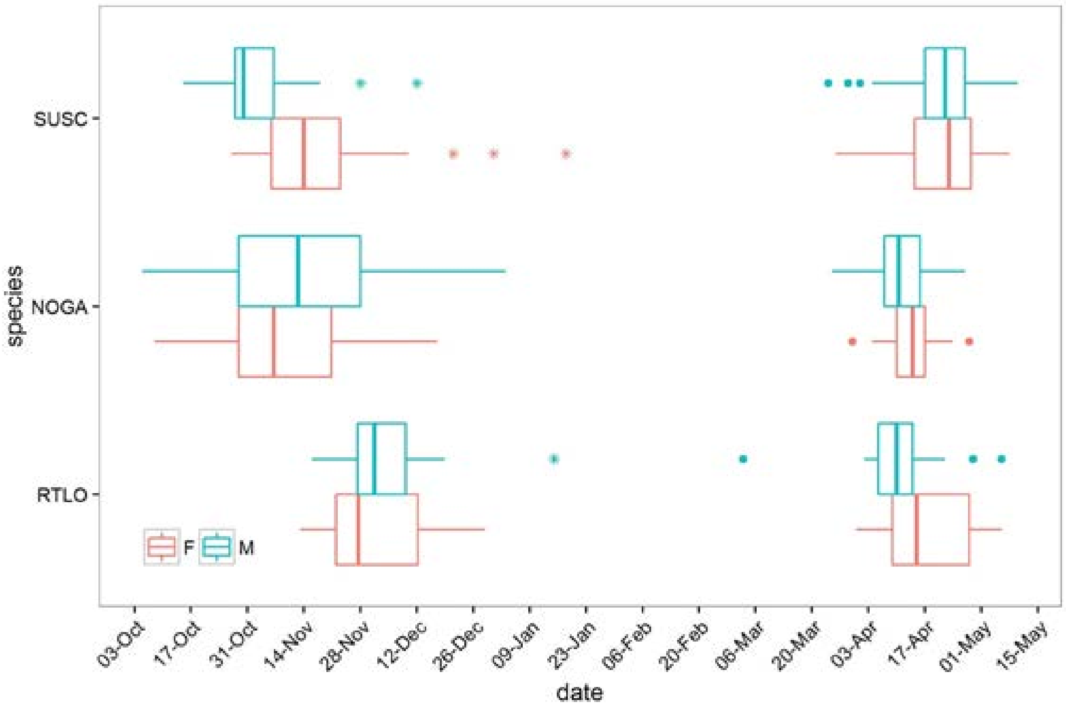

Figure 7-5. Boxplots showing average arrival (left) and departure (right) dates into the study area for adults of each species by sex.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.