Chapter 22: Wintering movements and habitat use of Northern Gannets (*Morus bassanus*) in the mid-Atlantic U.S.
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Chapter 22 Highlights

Wintering movements and habitat use of Northern Gannets (Morus bassanus) in the mid-Atlantic U.S.

Context[1]

Location data collected from satellite transmitters can be used to estimate home-range size and other features of the utilization distribution of target species. From these data, resource selection functions can be used to predict habitat use across landscapes or to understand the influence of certain habitat characteristics on a species distribution. We used this approach to analyze location data collected from satellite-tagged Northern Gannets captured at sea on their wintering grounds in the mid-Atlantic U.S., to determine occurrence and movement patterns in relation to potential offshore wind energy areas in the region. Similar analyses were conducted to examine movements of Surf Scoters (Chapter 20) and Red-throated Loons (Chapter 21), and time variant kernel density models were produced to examine the broad scale movement patterns of all three species throughout the year (Chapter 23). A companion chapter (Chapter 24) utilizes Northern Gannet telemetry data to understand more detailed behaviors, in addition to the movements and general habitat use information that is presented here. Northern Gannet interactions with offshore wind energy development are hypothesized to largely occur as a result of their foraging behaviors, so being able to differentiate between foraging and other behaviors in telemetry data will allow us to better determine areas of potential conflict between offshore wind energy development and Northern Gannet habitat use. Chapter 24 identifies locations that were consistently used by Northern Gannets for foraging, and what habitat characteristics defined these foraging areas.

Study goal/objectives

Investigate the spatial patterns, temporal patterns, and environmental variation in Northern Gannet migration and winter habitat use through a combination of satellite telemetry data and remotely collected environmental covariate information.

Highlights

- Northern Gannet core habitat from our sample included the protected inshore waters of the major bays and bay mouths. Although capable of roaming widely (up to 50 km from shore), most ocean locations were within 10 km of shore and in depths of around 20 m or less.
- Northern Gannets in our sample also used Outer Continental Shelf waters widely throughout the period in which they were present in the mid-Atlantic region. Individual Northern Gannets displayed rapid and extensive movements up and down the eastern seaboard over the course of the winter season, between the core use areas.

Implications

Broad-scale movements of Northern Gannets within the study area increase the likelihood that they would encounter offshore wind developments repeatedly throughout the winter, depending on size and the number of offshore facilities. Based on European studies, this exposure may lead to displacement of gannets from wind farm footprints or to collision mortality from turbines.

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[1] For more detailed context for this chapter, please see the introduction to Part V of this report.

Abstract

The Northern Gannet (*Morus bassanus*) is the largest seabird to breed 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, they breed at six colonies: three in the Gulf of St. Lawrence, Québec, and three off the eastern and southern coasts of Newfoundland. On migration, Northern Gannets move widely down the eastern seaboard to winter in the shelf waters of the mid-Atlantic region, the South Atlantic Bight, and the northern Gulf of Mexico (Nelson 1978, Fifield et al. 2014). In Europe, the Northern Gannet is highly ranked for collision risk with offshore wind turbines, and has also shown displacement from areas with offshore wind facilities (Johnston et al. 2014, Vanermen et al. 2015).

In the winters of 2011-12 and 2012-13, we captured 35 Northern Gannets and outfitted them with satellite tags, tracking their daily movements within the study area in winter, and their broader migratory movements throughout the remainder of the annual cycle. In each winter season, kernel density rasters were generated as a composite of sub-sampled points from one year's worth of tracking for each animal (for all animals surviving more than 60 days), to generate a composite wintering utilization distribution. Northern Gannets arrived in the wintering area between August 29 and December 17 (median date = November 3, n = 22), and departed for spring migration between February 23 and May 1 (median date = April 13, n = 33). Across all years, the extent of the winter composite (n = 17 pooled individuals) utilization distribution was 229,874 km^2, with the core use area totaling 42,360 km^2. Relative to the utilization distribution (i.e., the broader available area), Northern Gannet core-use areas were located in highly productive, shallower waters, with lower sea surface salinities, especially areas closer to shore, and over fine sandy substrate. In general, the core use areas included Delaware Bay, Chesapeake Bay, and Pamlico Sound, but Northern Gannets also used Outer Continental Shelf waters widely throughout the period in which they were present in the mid-Atlantic region.

Given the Northern Gannet's ubiquitous nature and its ability to range widely across the entire shelf region, the utilization distribution and core use areas observed in this study were large, increasing the likelihood of displacement due to offshore wind energy areas compared to other seabirds with smaller ranges.

Introduction

The global demand for sustainable energy sources, driven largely by the impacts of climate change, has led to the rapid development of wind energy in many countries. The United States has invested heavily in terrestrial wind energy generation, having installed over 46,000 turbines, generating over 62 gigawatts (GW) of energy (AWEA 2014). There is also substantial interest in developing offshore wind energy generation, particularly along the eastern seaboard, close to high population densities. The region also supports substantial natural resources, however, with unique ecological communities, including some 600,000 breeding pairs of 31 marine bird species (Nisbet et al. 2013).

The Northern Gannet (*Morus bassanus*) is the largest seabird to breed 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 also opportunistic and effective predators, foraging on 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 well-known 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, which represents ~27% of the global population, has experienced a healthy rate of growth since 1984 (4.4% per year), although that appears to have slowed in recent years (Chardine et al. 2013). On migration, Northern Gannets move widely down the east coast of Canada and the U.S. to winter in the shelf waters of the mid-Atlantic region, the South Atlantic Bight, and the northern Gulf of Mexico (Nelson 1978, Fifield et al. 2014). A very small proportion of the Newfoundland breeders are known to cross the North Atlantic to winter off of West Africa (Fifield et al. 2014). Like many seabirds, Northern Gannets display a low rate of reproduction and delayed maturation, initiating breeding at around 5 years of age and laying only one egg per year (Nelson 1978, Mowbray 2002). They are long-lived, with some birds known to have survived at least 20 years (Nelson 1978), and exhibit high adult survival (~95%; Chardine et al. 2013). These particular characteristics make the population vulnerable to any increase in adult mortality.

Northern Gannets are considered to be vulnerable to fatal collisions with offshore wind developments in European waters, due to their relatively poor maneuverability, and their habit of flying and plunge-diving from heights within the rotor-swept zone of wind turbines (Langston 2010). The Northern Gannet was ranked 8th in terms of collision risk in a recent study that compared the flight heights of 26 marine bird species with the heights of offshore wind turbines around the U.K., the North Sea, and along the Danish and Dutch coasts (Johnston et al. 2014). In addition to direct collision, Northern Gannets are likely vulnerable to other recognized hazards of offshore wind development, such as avoidance/displacement, and physical habitat modification (Fox et al. 2006). A recent study has shown avoidance by several marine bird species, including Northern Gannets, from a wind farm in the Belgian North Sea (Vanermen et al. 2015). Localized changes in prey populations and distributions could also affect Northern Gannets, as seen in other species (Perrow et al. 2011).

In order to assess the effects of disturbance and the potential population impacts of offshore wind development on Northern Gannets, basic information must be collected on their distribution and behavior, including flight pathways and timing of habitat use, within wind energy areas (WEAs). The distribution and abundance of marine birds in federal waters slated for offshore wind energy development have been the focus of ongoing aerial- and boat-based survey efforts in recent years (Parts II-III of this report, Geo-Marine, Inc. 2010, NFSC & SFSC 2012). However, few studies in North America have tracked individual marine birds to determine migratory and local within-season movements to evaluate potential interactions with proposed offshore wind energy developments. Location data collected from satellite transmitters can be used to estimate home-range size and other features of the utilization distribution of the target species. Kernel density estimation is a standard technique for characterizing and visualizing animal home ranges, and the utilization distribution is a probability density function that can be extended to quantify the relative frequency distribution of an animal's occurrence in space and time (Silverman 1986, Keating and Cherry 2004). Resource selection functions 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). Used resources are a subset of available resources, and a key factor in resource selection studies is determining what and how much will be included as "available" (Buskirk and Millspaugh 2006). The probability that particular habitats will be used by a species can be examined with a logistic regression model; however, decisions regarding sampling design, the underlying probability model, and assumptions must be carefully considered to ensure correct interpretation of results (Keating and Cherry 2004).

The objectives of this study were to track fine-scale winter movements of Northern Gannets in the mid-Atlantic region, identify regions of consistent use, and describe the timing of their annual migrations in and around the study area. Specifically, we captured adult Northern Gannets at a single breeding colony in eastern Canada in 2012 and in the mid-Atlantic region of the U.S. in winter in 2012 and 2013, and outfitted them with satellite tags (platform terminal transmitters, known as PTTs). Tags were attached either externally by taping them to the tail feathers (a tried and tested method for this species) or internally via surgical implantation (a novel method for this species). We then tracked their daily movements within the study area in winter, and their broader seasonal movements throughout the year.

Methods

Study area
The priority study area included federal waters off the mid-Atlantic U.S. coast from northern Delaware to the southern border of Virginia. 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 Northern Gannets were attempted in 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 in 2013 were focused in areas where high concentrations of target species were observed during the previous years' 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.

Satellite transmitters

Two satellite tracking devices were used in this study: Telonics IMPTAV-2630 (29 g, <1% of adult body weight) were used as tail-mounted devices in 2012, and Telonics IMPTAV-2640 (42 g) were implanted in birds in 2012 and 2013. Pre-surgery preparation of the implanted tags increased their weight to approximately 49 g (<2 % of adult body weight).

At-sea capture

In February and March of 2012 and 2013, Northern Gannets were captured at three sites in their wintering area in the mid-Atlantic region: the Chesapeake Bay, MD and VA (n=15), Delaware Bay, DE and NJ (n=5), and Pamlico Sound, NC (n=6). These birds were captured using a night-lighting technique, where birds were approached at night in a small boat, briefly disoriented with a powerful spotlight, and then captured with a dip net (Figure 22-1). All captured birds were weighed and banded with a standard U.S. Fish and Wildlife Service (USFWS) metal band. A blood sample (2-4 ml) was taken from the metatarsal vein of each individual for genetic determination of sex; only a small amount was required for this analysis, and the remainder was archived.

In 2012, three Northern Gannets captured in the wintering area had satellite tags taped to their central tail feathers using a combination of self-amalgamating tape (Tesa Tape, Inc., Charlotte, NC) and cable ties, and three other individuals had satellite tags surgically implanted (Figure 22-2). Birds with tail-taped tags were released immediately at the site of capture. In 2013, all birds captured in the wintering area received implanted transmitters (n=20). They were administered the sedative Midazolam upon capture, then transported to shore in adapted pet-carriers (plastic dog crates or totes). Surgical implantations of intra-abdominal PTTs with external antenna were conducted by qualified veterinarians, following standard techniques (Korschgen et al. 1996, Maulcahy & Esler 1999). After surgery, when birds were cleared for release by the veterinarian, they were returned to the general area of capture and released onto the water during daylight hours (Figure 22-3).

Colony capture

In late September 2012, adult Northern Gannets (n = 9) were captured on the nest at Cape St. Mary's, Newfoundland, during the fledging period using a telescoping noose pole. Satellite tags were attached to tail feathers using a combination of tape and cable ties (Figure 22-2). All captured birds were banded with a standard Canadian Wildlife Service (CWS) metal band, and a small (0.5 ml) blood sample was taken from the brachial vein for genetic sexing. Due to the need to release them as quickly as possible, not all were weighed.

Transmitter duty cycles

Tail-mounted tags were programmed to transmit intensively because Northern Gannet tail feathers are molted within a few months of capture. The tags deployed at the colony were programmed with a single duty cycle: 9 hours on and 4 hours off. The tail-mounted tags deployed at sea in winter were programmed with two distinct duty cycles: 4 hours on and 9 hours off (Feb 1-May 20) and 2 hours on

and 24 hours off (May 21-Sept 30), designed to provide the greatest resolution of movement while birds were expected to be in the mid-Atlantic region.

The batteries in the implanted satellite tags were expected to last up to a year or more, and these tags were programmed to transmit approximately daily throughout the winter months and migration periods, and approximately weekly during the breeding season. These tags were programmed with two distinct duty cycles: 4 hours on and 13 hours off (Sept 24-May 20) and 2 hours on and 120 hours off (May 21-Sept 23), designed to provide the greatest resolution of movement data during winter months, while prolonging the battery life for future transmissions.

Data processing and analysis

Satellite data were compiled and filtered using the Douglas Argos Filter[2] (DAF). 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, time of year, and the scale of the area under observation. With the DAF, data are retained if they pass a spatial redundancy test and/or a movement rate and turning angle test. Since our 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. Using DAF, we also identified the best representative point per duty cycle for each animal to reduce redundant daily positional information. All location data collected within 14 days of PTT deployment were excluded from analysis to reduce bias associated with surgery (Esler et al. 2000). The DAF also generates estimates of the distance between successive points (best representative point per duty cycle) and the amount of time between these points. Since the time between points varied between duty cycles and individuals, we also calculated the rate of distance moved by dividing distance moved by the number of hours between each duty cycle. These were calculated for the second winter period following deployment, which generally reflected movements from September to April.

A database of deployment and life-history data was built for each PTT tag deployed. Based on a close examination of the data, and the extent and direction of movement by each individual, we identified the following periods: breeding, molting, fall-staging, wintering, and spring-staging for every year that the animal was alive and/or tag transmitted.

Sensor data (e.g., temperature, voltage) could sometimes be used to determine the final fate of birds and tags. We assessed sensor data for every tag to identify confirmed mortality (by internal temperature sensor or mortality sensor) or battery/tag failure due to low voltage, and recorded the last known date alive for all birds confirmed dead during the period of tag activity. For all animals with tags that stopped transmitting, due to either low voltage or unknown reasons, we recorded the day after the last transmission as the last date of disposition. Tag duration dates were then calculated from the deployment start date to the final disposition date.

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[2] http://alaska.usgs.gov/science/biology/spatial/douglas.html

Kernel Density Estimation

We chose to represent only one year's worth of data per life period per animal. Each bird then only contributed one sample to each map, preventing any bias towards animals with more years of data due to tag longevity or mortality. We chose to include Year 2 data preferentially over Year 3 data, as few individuals provided a full third year of winter location data, and Year 1 data if only one year of data existed. We included only birds that transmitted >60 days after release to reduce bias from birds that could have been negatively affected by transmitter implantation and handling.

Kernel density maps were created for the wintering period. Kernel density estimation involves the use of point data from telemetry to estimate relative spatial use during specified time intervals. For each location, the bird's habitat use was estimated to have been greatest directly on the point, and to decrease with distance from the point (reaching zero at a bandwidth specified by the user, after Worton 1989). Following Loring et al. (2014), we used the composite KDE method (with Gaussian kernel and Likelihood cross-validation bandwith estimator), where S random points are selected for n individuals and pooled to create a single composite KDE representing the utilization distribution of all animals. We defined S by the lower quartile of the number of points per animal represented in the winter period (S = 32, n= 17). The 0.95 utilization distribution and 0.5 core habitat use isopleths were generated from the composite KDEs. These isopleths were then used for further analyses.

Individual Home Range Estimation

We calculated the home range sizes of individuals during winter by estimating the minimum convex polygon (mcp) areas (km^2) using package adehabitatHR version 0.4.13 (Calenge 2006) in R version 3.1.1 (R Core Team 2014) and removing 5% outliers. Only animals transmitting for at least 30 days were used.

Environmental covariates and habitat selection

We examined third-order resource selection of Northern Gannets to determine characteristics of preferred habitats that can be used to predict probability of use across the study area. Using the composite kernel density estimates, we defined "used" or core use areas as telemetry point locations within the 0.50 isopleth, and compared the habitat characteristics of those points to randomly-generated points throughout the 0.95 utilization distribution, defined as "available" locations (sampling protocol-A; 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 (degrees Celsius), 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), seafloor slope (degrees), and sediment grain type. We measured water depth (m) and slope (degrees) 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 (m) 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). Estimates of seafloor slope were obtained from the Nature Conservancy's Northwest Atlantic Marine Ecoregional Assessment data portal. The benthic habitat layer contains an estimate of slope, which is calculated as the difference in elevation between two neighboring raster cells, expressed in degrees, and were grouped accordingly: (1)

0-0.015° = level flat; (2) 0.015-0.05° = flat; (3) 0.05-0.80° = gentle slope; 0.80-8.0° = slope; and >8.0° = steep slope (Greene et al. 2010). 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 create seasonal and long-term winter mean climatology rasters for sea surface temperature, chlorophyll *a*, and sea surface salinity (Roberts et al. 2010). We smoothed daily surface temperature 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 0.054 degrees latitude and longitude. Sea surface salinity was estimated using the HYbrid Coordinate Ocean Model (HYCOM) produced by the National Ocean Partnership Program at a spatial scale of 1/12 degrees latitude and longitude (Chassignet et al. 2009). 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).

We used logistic regression to model habitat covariate effects on used versus available locations over three winter periods (2011-2012, 2012-2013, and 2013-2014) within the study area. Candidate models were developed for each winter period and for all years combined. Development of models was exploratory, but, based on a priori knowledge of Northern Gannet habitat, we predicted that used locations would be related to nine habitat covariates: depth, distance to shore (dist), long-term (chlor10) and seasonal (chlorw) chlorophyll *a*, long-term (sst10) and seasonal (sstw) sea surface temperature, long-term (sss6) and seasonal (sssw) sea surface salinity, and seafloor slope. Correlations between pairs of habitat variables were quantified using a Pearson product-moment correlation matrix. Multicollinearity among covariates was assessed by calculating variance inflation factors (VIF). Highly correlated variables included: (1) long-term to seasonal sea surface temperature, (2) long-term to seasonal salinity, and (3) long-term to season chlorophyll *a* concentration. Therefore, models included the long-term or seasonal term for each of those variables, but not both. All other pairwise comparisons had correlations of < 0.50 and VIF values of < 2.0 and were retained as variables in the modeling process, resulting in six variables considered for inclusion in each model. The square of both water depth and distance to shore were also included in order to examine the possibility that their relationship to the log odds of habitat use was curvilinear rather than linear. Additionally, the product of each pair of continuous variables was included to assess possible interactions among the predictors. 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.

Results

Capture and PTT deployment

A total of 35 Northern Gannets were satellite tagged in 2012 (*n*=15) and 2013 (*n*=20), of which 15 were female, 19 were male, and 1 was undetermined. Body mass of females ranged from 3,050 to 3,700 g ($\bar{x}$ = 3,329 ± 240 g, *n* = 14), and for males ranged from 2,675 to 4,050 ($\bar{x}$ = 3,258 ± 358 g, *n* = 14).

In all, 12 of these Northern Gannets were equipped with tail-taped tags, and 23 had tags surgically implanted. Nine were captured at the breeding colony at Cape St. Mary's, Newfoundland, in 2012, and 26 were captured while wintering at sea in the mid-Atlantic study area (6 in 2012 and 20 in 2013).

General migratory movements

In the latter half of March, satellite tagged birds were generally located inshore in the mid-Atlantic region, or in the broad shelf waters of the Gulf of Mexico (Figure 22-4). April marked the beginning of movements north. Migrating Northern Gannets generally departed the Mid-Atlantic area in early to mid-April and arrived in the region of their breeding colony in late April/early-May. Migration was highly asynchronous, however, as some individuals reached their breeding colony before others had even left the wintering area.

All of the Northern Gannets tagged in the winters of 2011-12 and 2012-13 that reached the breeding grounds appeared to breed at colonies in Québec, particularly Bonaventure Island, off the eastern tip of the Gaspé Peninsula, and Bird Rocks in the Magdalen Islands archipelago. Some individuals made extensive foraging trips from these colonies, ranging from the upper Gulf of St. Lawrence to the Labrador Sea. Owing to a pervasive broad scale warm-water perturbation in the western Atlantic during the summer of 2012, many Northern Gannets at Bonaventure Island and at Cape St. Mary's made inordinately long foraging trips from their breeding sites and experienced very low reproductive success (Montevecchi et al. 2013).

PTT-equipped Northern Gannets began their southerly migration in September (Figure 22-5). One adult from Cape St. Mary's, and another captured in the study area in the winter of 2012, passed through the mid-Atlantic study area to winter in the Gulf of Mexico. The birds that reached the Gulf of Mexico remained there through the early winter. The birds that departed the breeding area later in the fall largely spent their early winter offshore in the mid-Atlantic region. By mid- to late-winter, activity was once again concentrated in the mid-Atlantic region.

In general, Northern Gannets showed a high use of relatively shallow, coastal waters (<30 m) during their migrations. There is some indication that males tended to exhibit a more northerly distribution in their wintering range, and, as a result, may spend more time in the mid-Atlantic area than females.

Winter area use

Northern Gannets arrived in the wintering area between August 29 and January 1 (median date = November 3, *n* = 22), and departed for spring migration between February 23 and May 1 (median date = April 13, *n* = 33). Data from the second winter after tagging provides some indication that males may arrive in the study area later than females (male median date = November 22, range = Nov 20-Jan 3, *n* =

4; female median date = November 13, range = Oct 25-Dec 17, *n* = 6) and depart earlier (male median date = February 13, range = Jan 3-Mar 18, *n* = 4; female median date = March 11, range = Dec 27-Mar 26, *n* = 6), although sample sizes are admittedly small at this point. The average length of stay in the wintering area for both sexes combined was 85 days (*n* = 12; range = 37-152 days). This is likely an underestimate, however, since Northern Gannets were caught mid-winter, and we did not get data for a full winter until one year later, at which point the satellite tags were reaching their expected lifespan.

Wintering movements of individual birds in the study area varied considerably. The minimum distance moved by a bird between the best points in consecutive 17-hour duty cycles was 0.5 km, while the maximum distance moved was 1,059 km. On average, birds moved 22-370 km ($\bar{x}$ = 87.5 ± 118.9 km, *n*=11) between duty cycles. These estimates were based on the best quality location per duty cycle derived from the DAF filtered data for each animal, and the amount of time between these points varied between duty cycles and individuals; therefore, we also calculated the rate of distance moved by dividing distance moved by the number of hours between each point. The minimum distance traveled per hour during the second winter season was 0.01 km/hr, the maximum was 10.9 km/hr. On average birds traveled 0.4-2.1 km/hr ($\bar{x}$ = 1.4 ± 0.5 km/hr, *n* = 11) between duty cycles.

Northern Gannet wintering home ranges also varied widely. During the second winter period following deployment, individual home ranges varied from 3,961-128,590 km^2 ($\bar{x}$ = 28,734 ± 38,630 km^2; *n* = 9). There is some suggestion that females may have roamed more widely than males (females $\bar{x}$ = 17,353 ± 10,386 km^2, range = 7,091-31,756 km^2, *n* = 9; males $\bar{x}$ = 15,498 ± 16,315 km^2, range = 3,961-27,034 km^2, *n* = 9), although sample sizes are too small to examine this quantitatively. This may be a result of males potentially being present in the study area for shorter periods in winter than females.

Winter habitat selection
The core use areas of wintering male and female Northern Gannets included Delaware Bay, Chesapeake Bay, and Pamlico Sound, but individual Northern Gannets roamed widely across the area in each wintering period, showing low site fidelity within seasons. Although individual Northern Gannets ranged widely, and often visited several core use areas (even on a daily basis), the general locations used by wintering Northern Gannets were relatively consistent. Across all years, the extent of the winter composite (*n* = 17 pooled individuals) utilization distribution was 229,874 km^2, with the core use area totaling 42,360 km^2 (Figure 22-6).

Relative to the utilization distribution (i.e., the broader available area), Northern Gannet core-use areas were located in highly productive, shallower waters, with lower sea surface salinities, especially areas closer to shore (Table 22-1), and over fine sandy substrate (Table 22-2). The highest-ranked habitat selection model differed slightly between years (Table 22-3). The top model for all years of data combined accounted for 0.67 of Akaike weight, and indicated a positive effect of long-term chlorophyll *a* on habitat use, and a negative effect of depth, distance to shore, and long-term salinity (Table 22-3). Other coefficients included in the top model had confidence intervals that included zero and were not considered reliable (Table 22-3 to Table 22-4). Among sediment types, the greatest frequency of use associated with core use areas consisted of very fine to fine sandy bottoms with grain sizes that ranged from 0.03-0.35 mm (Table 22-2).

Discussion

The results from this study confirm the importance of the mid-Atlantic region for wintering and migrating Northern Gannets. Birds first arrived in the mid-Atlantic in August, with peak arrival time around November, departing again mostly in April. While in the study area, Northern Gannets used the Outer Continental Shelf waters broadly in winter, with core habitat including the protected inshore waters of the major bays and bay mouths, including the Delaware Bay and Chesapeake Bay areas. Satellite tracking to date also suggests that Northern Gannets show relatively weak winter site fidelity from year to year. Individual Northern Gannets also displayed rapid and extensive movements up and down the eastern seaboard over the course of the winter season, between the core use areas, which increases the likelihood that they would encounter offshore wind developments repeatedly throughout the winter.

This study has also confirmed that Bonaventure Island, Québec (the Northern Gannets' largest North American colony; Chardine et al. 2013), and Cape St. Mary's, Newfoundland (the species' southernmost colony in North America; Montevecchi et al. 2013) are colonies of origin for Northern Gannets using mid-Atlantic waters, although birds from all six North American colonies most likely use the region in winter. As they migrate south from breeding colonies during autumn, Northern Gannets generally move into coastal waters (Fifeld et al. 2014). There is some suggestion in the tracking data that this inshore movement is more pronounced among females than males, and that females may move further south than males, but this will be examined further in future analyses. The greater movement south could explain why females departed the study area slightly later, or this difference may be driven by the males need to return to the breeding colony early in order to reclaim ownership of their nest site (nest sites are known to be established and held by males; Mowbray 2002).

Important foraging and habitat use areas for Northern Gannets appear to be defined by a wide variety of habitat characteristics. Thus, development activities anywhere within the study area could potentially affect gannets, but this is most likely in the western half of the study area, where gannets were more abundant. Overall, Northern Gannets used shallow (<20 m) areas around 10 km from shore, although they also ranged well out onto the Outer Continental Shelf, up to 50 km. Northern Gannets are capable of frequent and long-distance movements in search of ephemeral epipelagic prey (Hamer et al. 2007, Wakefield et al. 2013), and can easily move between the core wintering areas in the mid-Atlantic region. Not surprisingly, the utilization distribution and core use areas observed in this study were large compared to other marine birds wintering in the area, such as Surf Scoters (Chapter 20) and Red-throated Loons (Chapter 21). Placement of offshore wind energy facilities in shallow (<30 m) inshore areas near the mouths of large bays, in the designated WEAs, or elsewhere within the study area, could potentially affect Northern Gannets in several ways: by increasing mortality due to direct collision (Furness et al. 2013), displacing them from high-quality foraging areas (Vanermen et al. 2015), or increasing energy expenditures through added flight costs to avoid turbines (Masden et al. 2010).

There was wide variation in estimates of individual home range size, distances moved, and the rate of distance moved by individuals between duty cycles. This variability was potentially driven by multiple factors, such as the specific locations and dates of capture, as well as true variations in movement

patterns between individuals. The significance of these effects will be explored more thoroughly in future modeling efforts that incorporate additional years of data and can potentially provide a more accurate description of Northern Gannet home range size on its wintering grounds in the mid-Atlantic region.

The large winter ranges of Northern Gannets documented in this study, however, probably increase the likelihood of displacement due to development within offshore WEAs compared to other seabirds with smaller ranges. Significant stressors already exist for this species on the wintering grounds, including exposure to pesticides and other contaminants, such as mercury and PCBs (Champoux et al. 2015), oil spills (Montevecchi et al. 2012), mortality from bycatch in fishing nets (Lanza 1998, Forsell 1999, Žydelis et al. 2013), and changes to fish distributions due to climate change (Nye et al. 2009). Additional mortalities in the wintering area, or indirect effects such as displacement, could have detrimental effects on the North American breeding population of Northern Gannets, and it is critical that important foraging areas and flight pathways of this and other sensitive bird species are identified and considered during the planning and development phases of offshore wind energy development. We will continue to pursue this analysis to achieve these objectives, and our results will be forthcoming in an anticipated manuscript publication in 2016.

Next steps
This preliminary analysis includes data from two years of a broader four-year study. Future analyses will include additional data gathered from satellite tagged birds during the 2013-14 and 2014-15 winter periods. The inclusion of these additional data will also allow for more thorough and comprehensive analysis of wintering movements, home range sizes, and habitat selection and use. Habitat covariate data used in modeling will also be updated to include long-term mean values that match the duration of the tracking data. Ultimately, this is hoped to improve model fit and/or uncover new interactions between covariates not highlighted in the existing analysis.

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Figures and tables

Figure 22-1. Basic night-lighting technique used to capture Northern Gannets at sea in their wintering area. (Photograph: J. Fiely/BRI)

Figure 22-2. Satellite transmitter attachment in Northern Gannets – externally taped to the underside of the central tail feathers (*left*) and surgical implantation (*right*). (Photographs: J. Fiely/BRI)
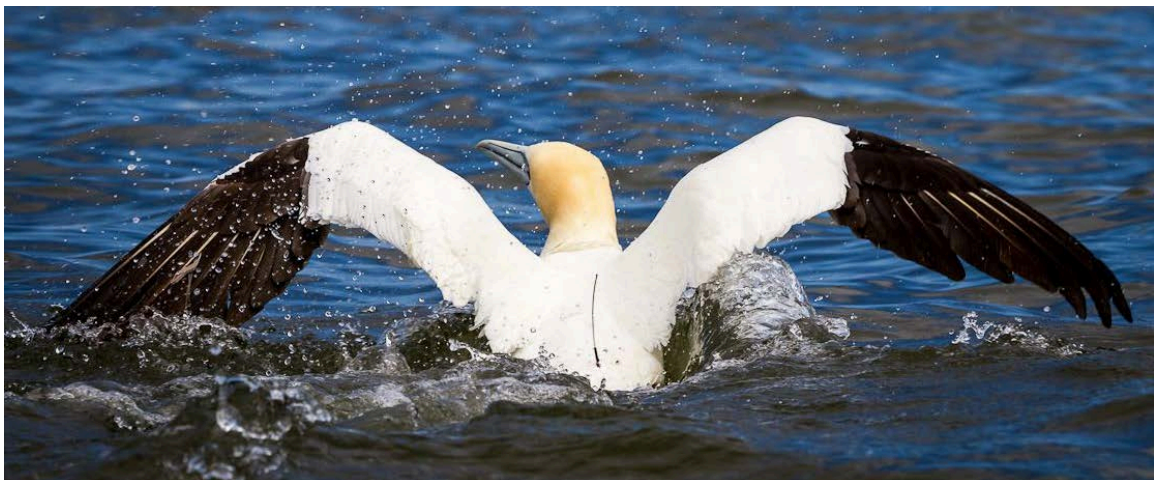
Figure 22-3. A Northern Gannet with an implanted satellite transmitter (the protruding antenna clearly visible on the lower back) being released in Delaware Bay, MD, in 2013. (Photograph: J. Fiely/BRI).

Figure 22-4. The spring migration of Northern Gannets across the eastern seaboard (*left*) and within the study area (*right*). Lines do not necessarily represent direct flight paths. Symbols indicate the endpoints for breeding in the Gulf of St. Lawrence (+), and the general wintering areas in the mid-Atlantic and the Gulf of Mexico (Δ) for males (grey) and females (red).

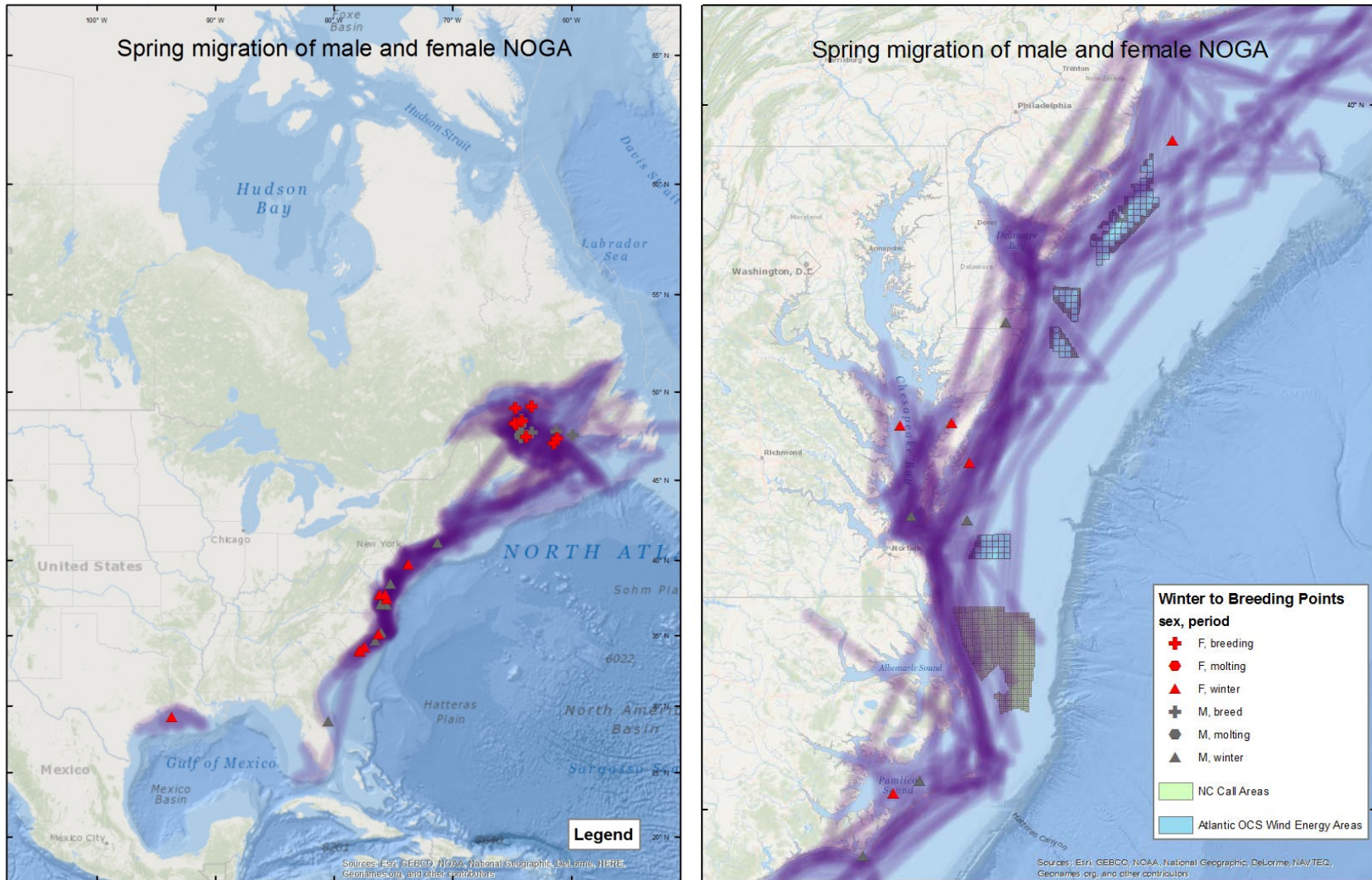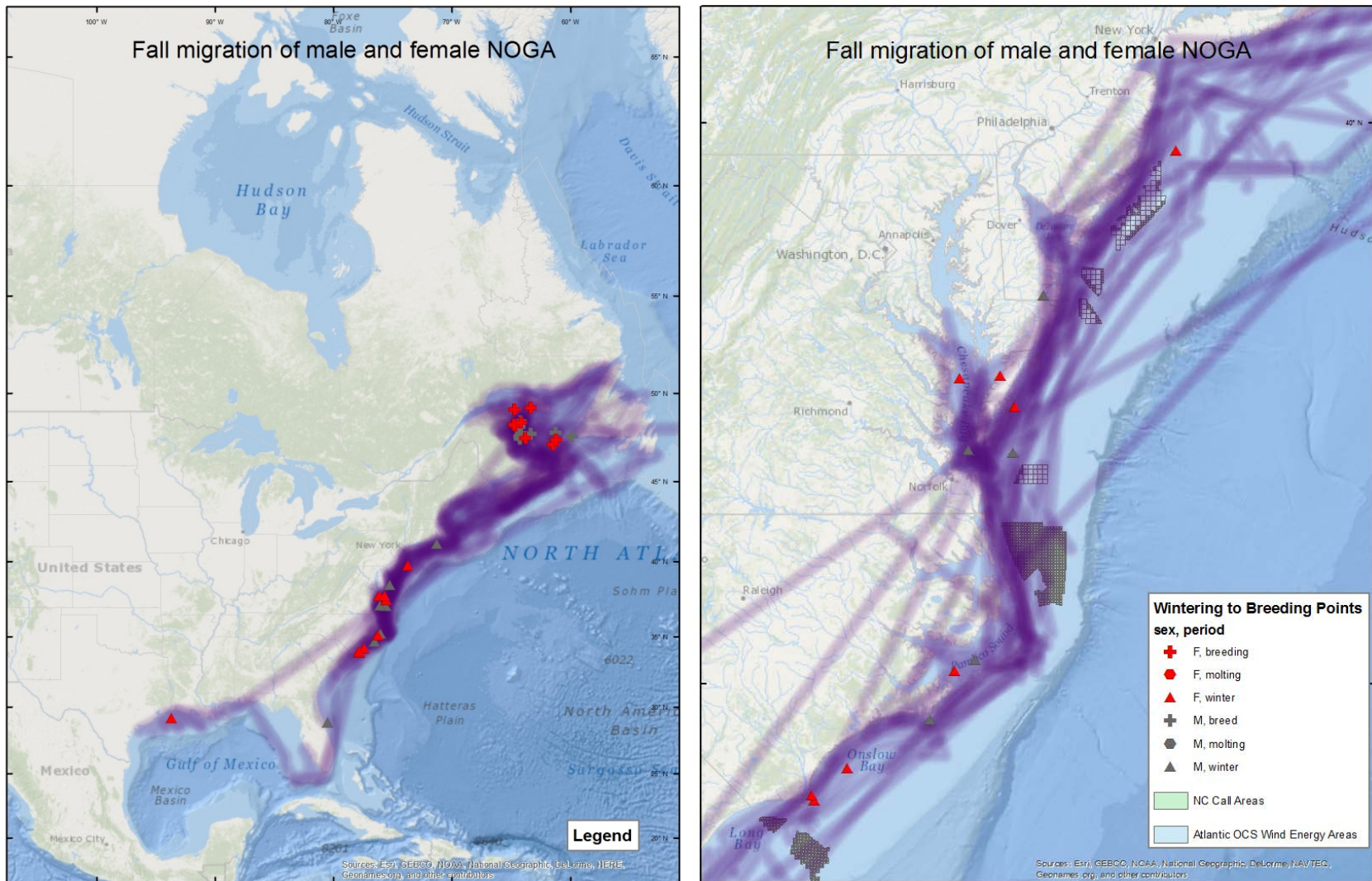**Figure 22-5. The autumn migration of Northern Gannets across the eastern seaboard (*left*) and within the study area (*right*).** Lines do not necessarily represent direct flight paths. Symbols indicate the endpoints for breeding in the Gulf of St. Lawrence (₊), and the general wintering areas in the mid-Atlantic and Gulf of Mexico (Δ) for males (grey) and females (red).

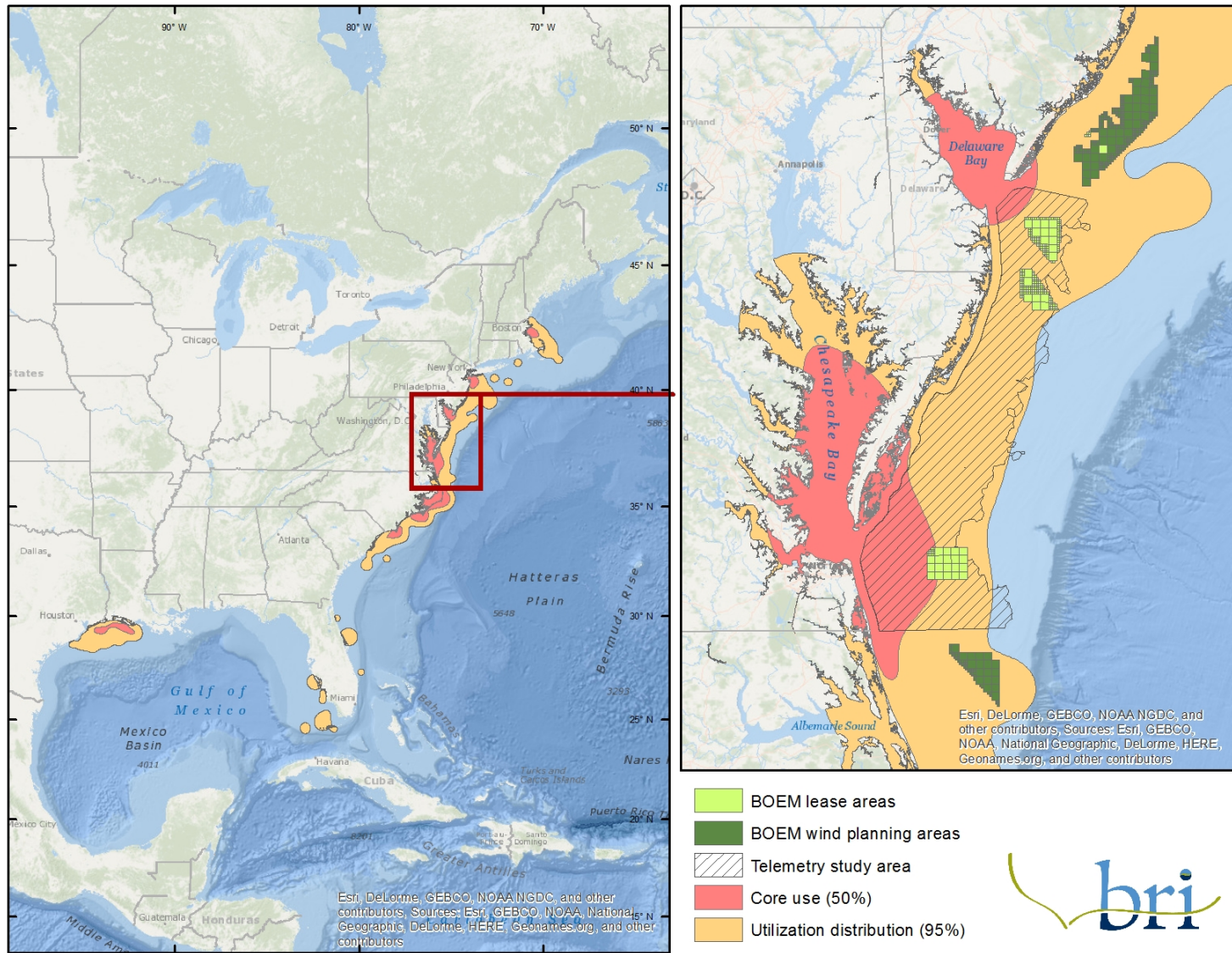**Figure 22-6. The overall utilization distribution (orange) and core use (red) areas based on satellite-derived locations for Northern Gannets, and in relation to the BOEM lease areas and wind planning areas (inset).** Within the broader mid-Atlantic study area, core use includes Delaware Bay and Chesapeake Bay.

Table 22-1. Range, mean ($\overline{x}$) and standard error (SE) of habitat variables at satellite-derived locations for Northern Gannets in the core use area (0.5 isopleth) and for random points across the utilization distribution (available; 0.95 isopleth).

Habitat Variable	Abbr.	Units	Available		Core Use	
			range	$\overline{x}$ ± SE	range	$\overline{x}$ ± SE
Long-term						
Chlorophyll *a* - 10 yr Mean	chlor10	mg/m^3	0 - 33.6	2.9 ± 0.07	0 - 32.9	6.4 ± 0.16
Sea Surface Temperature – 10 yr Mean	sst10	°C	0 - 24.9	13.1 ± 0.11	0 - 18.7	10.0 ± 0.17
Mean Sea Surface Salinity	sss6	psu^1	18.8 - 36.3	34.3 ± 0.03	16.8 - 35.8	32.9 ± 0.12
Physical						
Depth	depth	m	0.1 – 2,491	37.3 ± 2.22	0.1 - 98.1	12.4 ± 0.38
Slope	slope	degrees	<0.001 - 12.8	0.19 ± 0.011	<0.001 - 3.1	0.17 ± 0.009
Distance to Shore	dist	km	0.1 – 133.2	32.8 ± 0.53	0.1 – 50.5	10.1 ± 0.31
Short-term						
Chlorophyll *a* - seasonal	chlorw	mg/m^3	0.12 - 56.2	2.93 ± 0.07	0.95 - 38.9	6.2 ± 0.16
Sea Surface Temperature - seasonal	sstw	°C	2.8 - 25.6	13.9 ± 0.11	3.1 - 20.8	10.3 ± 0.17
Sea Surface Salinity - seasonal	sssw	psu^1	19.0 - 36.5	34.4 ± 0.03	16.5 - 36.0	33.0 ± 0.12

[1] psu = practical salinity units

Table 22-2. Proportion of use of different sediment types at satellite-derived locations for Northern Gannets in the core use area (0.5 isopleth) and for random points across the utilization distribution (available; 0.95 isopleth).

Sediment Grain		Available		Core Use	
Size (mm)	Type	n	% Use	n	% Use
0.00 - 0.03	Silt/Mud	81	7	32	5
0.03 - 0.17	Very Fine Sand	209	17	154	26
0.17 - 0.35	Fine Sand	282	23	209	36
0.35 - 0.36	Sand	154	13	38	6
0.36 - 0.48	Medium Sand	152	13	54	9
0.48 +	Coarse Sand - Gravel	329	27	98	17

Table 22-3. Logistic model selection results examining the annual effects of water depth (dep), distance from shore (dist), sediment type (sed), slope (slope), long-term mean chlorophyll *a* concentration (2004-2014; chlor10), long-term mean winter sea surface temperature (2004-2014; sst10), long-term mean sea surface salinity (2008-2014; sss6), seasonal mean winter chlorophyll *a* concentration (chlorw), seasonal mean winter sea surface temperature (sstw), and seasonal mean winter sea surface salinity (sssw) on the resource selection of Northern Gannets wintering in the mid-Atlantic U.S. Models are ranked according to Akaike Information Criterion adjusted for small sample size (AICc). The table shows the variables included in each model, differences between model AICc values (ΔAICc), and AICc weights (w_i). Only models with ΔAICc values < 7 were included in the table.

Winter Period and Model	AIC_c	ΔAIC_c	w_i
2011 - 2012			
sed+chlor10+sstw+slope	34.587	0.000	0.374
sed+chlor10+sss6+slope	35.161	0.574	0.280
sed+chlor10+sstw+slope+(chlor10*sstw)	37.034	2.447	0.110
sed+chlor10+sssw+slope	37.037	2.450	0.110
sed+dist^2+chlor10+sss6+slope	37.717	3.130	0.078
sed+chlorw+sstw+slope	40.407	5.820	0.020
sed+dist^2+chlor10+sss6+slope+(chlor10*sss6)	40.411	5.824	0.020
2012 - 2013			
dep+sed+dist^2+chlor10+sss6	462.933	0.000	0.496
dep+sed+dist^2+chlor10+sss6+(chlor10*sss6)	464.306	1.373	0.250
dep+sed+dist^2+chlorw+sssw	464.816	1.883	0.194
dep+sed+dist^2+chlorw+sssw+(chlorw*sssw)	467.305	4.372	0.056
2013 - 2014			
sed+dist^2+chlor10+sss6+slope	420.539	0.000	0.591
sed+dist^2+chlor10+sss6	423.638	3.107	0.125
dep+sed+dist^2+chlor10+sss6	423.280	2.749	0.150
sed+dist^2+chlor10+sss6	423.638	3.107	0.125
All Years			
dep+sed+dist^2+chlor10+sss6	1017.190	0.000	0.671
dep^2+sed+dist^2+chlor10+sss6	1020.200	3.010	0.149
dep+sed+dist^2+chlor10+sssw	1021.170	3.980	0.092
dep+sed+dist^2+chlorw+sss6	1022.830	5.640	0.040

Table 22-4. Coefficients (β) and 95% confidence intervals (lower and upper) of best-fit resource selection model for Northern Gannets wintering in the mid-Atlantic region in 2012-2013.

Model Years and Variable	β	Lower	Upper
2011 - 2012			
Long-term chlorophyll *a* (mg/m^3)	1.576	0.313	3.63
Seasonal sea surface temperature (°C)	-5.733	-13.809	-2.613
Slope (°)	-19.135	-43.389	-6.24
Sediment grain size (mm) and type			
0 - 0.03 silt/mud	-28.332	-65.765	-11.300
0.03 - 0.17 very fine sand	5.468	1.123	14.926
0.17 - 0.35 fine sand	5.08	1.798	12.020
0.35 - 0.36 sand	3.157	-2.494	11.271
0.36 - 0.48 medium sand	8.217	2.302	21.966
2012 – 2013			
Long-term chlorophyll *a* (mg/m^3)	0.051	-0.041	0.148
Long-term sea surface salinity (psu)	-0.148	-0.335	-0.011
Distance to shore^2 (km)	-1.449*10^{-9}	-2.584*10^{-9}	-5.529*10^{-10}
Depth (m)	-0.118	-0.164	-0.077
Sediment grain size (mm) and type			
0 - 0.03 silt/mud	-0.819	-2.41	0.587
0.03 - 0.17 very fine sand	0.481	-0.047	1.018
0.17 - 0.35 fine sand	0.14	-0.338	0.629
0.35 - 0.36 sand	1.131	0.407	1.868
0.36 - 0.48 medium sand	0.133	-0.517	0.779
2013 – 2014			
Long-term chlorophyll *a* (mg/m^3)	-0.003	-0.118	0.117
Seasonal sea surface temperature (°C)	-0.373	-0.672	-0.079
Seasonal sea surface salinity (psu)	0.691	0.167	1.218
Seasonal sea surface temperature* seasonal sea surface salinity	0.172	0.044	0.302
Distance to shore^2 (km)	-1.662*10^{-9}	-2.387*10^{-9}	-1.045*10^{-9}
Depth (m)	-0.0113	0.027	-0.0001
Sediment grain size (mm) and type			
0 - 0.03 silt/mud	0.547	-0.585	1.742
0.03 - 0.17 very fine sand	-0.025	-0.625	0.565
0.17 - 0.35 fine sand	0.457	-0.043	0.961
0.35 - 0.36 sand	-0.539	-1.487	0.327
0.36 - 0.48 medium sand	-0.332	-1.005	0.316
All Years			
Long-term chlorophyll *a* (mg/m^3)	0.072	0.011	0.137
Long-term sea surface salinity (psu)	-0.106	-0.219	-0.013
Distance to shore^2 (km)	-1.899*10^{-9}	-2.449*10^{-9}	-1.417*10^{-9}
Depth (m)	-0.022	-0.035	-0.011
Sediment grain size (mm) and type (mm)			
0 - 0.03 silt/mud	-0.091	-0.963	0.744
0.03 - 0.17 very fine sand	0.313	-0.043	0.669
0.17 - 0.35 fine sand	0.205	-0.099	0.512
0.35 - 0.36 sand	0.220	-0.264	0.695
0.36 - 0.48 medium sand	-0.219	-0.645	0.197