Chapter 21: Wintering movements and habitat use of Red-throated Loons (*Gavia stellata*) in the mid-Atlantic U.S.

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Carrie E. Gray, Andrew T. Gilbert, Jeffrey Tash, and Carl Anderson

Biodiversity Research Institute, Portland, ME

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Chapter 21 Highlights

Wintering movements and habitat use of Red-throated Loons (Gavia stellata) tracked via satellite telemetry 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. Kernel density estimation is a standard technique for characterizing and visualizing animal home ranges, and the utilization distribution estimates the intensity or probability of use by an animal throughout its home range. 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 Red-throated Loons 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 Northern Gannets (Chapter 22), and time variant kernel density models were produced to examine the broad scale movement patterns of all three species throughout the year (Chapter 23).

Study goal/objectives

Improve our understanding of wintering Red-throated Loon movements and seasonal use of space in the mid-Atlantic study area.

Highlights

- Composite kernel density estimate (KDE) maps calculated in GIS, using location data for each loon, provide information on core use areas within the study area during winter.
- We identify key habitats for Red-throated Loons on their wintering grounds and during migration, as well as the timing of their use.
- Wintering loons in our sample used tidal rivers, bays, and ocean locations, and core use areas were generally 5-10 km from shore. Most ocean locations did not exceed 5 km from shore and were decidedly in the "nearshore" environment. Accordingly, water depth associated with use was shallow, with more than half the locations not exceeding 13 m.

Implications

Quantifying the habitat characteristics within core use areas produced reliable information regarding Red-throated Loon habitat use in the mid-Atlantic region. This information can be paired with distribution and abundance data derived from surveys (Parts II-IV of this report) to more thoroughly describe the distribution patterns of this species in the region and determine potential exposure to future offshore wind energy development.

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

Abstract
The Red-throated Loon (*Gavia stellata*) is listed by the U.S. Fish and Wildlife Service (USFWS) as a species of conservation concern in much of its Arctic breeding range and wintering grounds in the Atlantic Flyway. However, data gaps exist regarding this species' wintering distributions, including concentration and timing of use, as well as migratory routes and stopover areas. In 2012 and 2013, we captured Red-throated Loons at sea on their wintering grounds in the Mid-Atlantic region and tagged them with platform terminal transmitters (PTTs) as part of a project focused on offshore wind energy development and diving birds. We used satellite tracking to map winter use movements in the mid-Atlantic study area and migratory routes of individuals (N = 23) to and from breeding locations in Quebec, Nunavut, Northwest Territories, and Greenland. We calculated composite kernel density (KDE) maps using GIS from movement data for each loon. 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.

Areas of heaviest habitat use were observed around the mouth of the Chesapeake Bay, south along the coast to the Virginia/North Carolina border, and the central eastern portion of Pamlico Sound and coastal waters off Cape Hatteras National Seashore in North Carolina. Small areas in central and northern Chesapeake Bay, as well as areas along the Delaware coast and Delaware Bay, were also heavily used by loons in our sample. Spring migration stopover sites included Long Island Sound, Narragansett Bay, Nantucket Sound, Buzzards Bay, Bay of Fundy, Gulf of St. Lawrence, and the St. Lawrence River; autumn stopover sites included Hudson Bay, James Bay, Hudson Strait, Ungava Bay, Gulf of St. Lawrence, and Lake Ontario. These results identify key habitats for Red-throated Loons on their wintering grounds and during migration, as well as the timing of their use.

Introduction
Increased interest in renewable energy has led to the identification of offshore Wind Energy Areas (WEAs) for potential development in U.S. coastal waters. Wind energy is associated with fewer environmental degradation 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, Goodale and Milman 2014). Specifically, Fox et al. (2006) described three primary factors: the potential for collision mortality, displacement from key foraging areas and migration and feeding flight pathways, and physical habitat loss associated with construction. 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). For example, Red-throated Loons (*Gavia stellata*) and Arctic Loons (*G. arctica*) were present in average densities prior to construction of a wind farm in coastal waters off Denmark, but showed complete avoidance of the area during the construction phase and 3-yr post-construction period (Petersen et al. 2006). Further, this avoidance effect extended to a distance of 2 km around the wind farm. Indeed, multiple papers have identified the Red-throated Loon as a species vulnerable to this type of disturbance or displacement (Petersen et al. 2006, Halley and Hopshaug 2007, Percival 2014, Furness et al. 2013). Bird species with a high proportion of their biogeographic population occurring in offshore development areas, and those

with high adult survival, are considered most vulnerable to population declines (Desholm 2009). In particular, 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). 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).

Red-throated Loons have a circumpolar breeding distribution, nesting primarily on remote ponds in coastal tundra habitat. Similar to other loons, they are long-lived (likely 25-30 years) and experience high adult survival (≈ 0.92; Barr et al. 2000, Schmutz 2014). In North America, they winter along both coasts, as far south as northern Georgia on the Atlantic Coast, and northern Baja California and the Sea of Cortez on the Pacific Coast (Barr et al. 2000). 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 Alaska Red-throated Loon population declined by 53% from approximately 21,000 birds in 1977 to 10,000 in 1993 (Groves et al. 1996). Recent surveys in the Baltic Sea documented another alarming decline of 84% in wintering loon populations between 1988-1993 and 2007-2009 survey periods, the majority of which were estimated to be Red-throated Loons (Skov et al. 2011).

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 (Forsell 1999, Root 1988). 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). In order to assess the effects of disturbance and the potential population impacts of offshore wind development on Red-throated Loons, basic information must be collected on their distribution and behavior, including flight pathways and timing of habitat use, within proposed 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 and SFSC 2012). Few studies in North America have tracked individual marine birds, however, 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 target species. Kernel density estimation is a standard technique for characterizing and visualizing animal home ranges, and identifying the utilization distributions 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). 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 (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).

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 Huppop 2004, Furness et al. 2013, Robinson Willmott et al. 2013), (2) a large proportion of their biogeographic population winters in this region (Forsell 1999, Root 1988), (3) they are designated as a US Fish and Wildlife Service (USFWS) "species of conservation concern" on their wintering grounds along the New England and Mid-Atlantic Coast (USFWS 2008), and (4) they have previously been successfully tracked using satellite transmitters (Schmutz et al. 2009). Consequently, 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.

Methods

Study area

The priority study area included federal waters off the mid-Atlantic U.S. coast from southern New Jersey to the southern border of North Carolina. 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; Figure 21-1). In 2012, capture efforts for Red-throated Loons were focused 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 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 (Figure 21-1).

Capture and PTT deployment

We used satellite telemetry to track the locations of Red-throated Loons on their wintering grounds in the mid-Atlantic study area. Loons were deployed with abdominal-implanted platform terminal satellite transmitters (PTTs) from several capture locations during 2012 and 2013 (Table 21-1). 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 (2008) 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 US Fish & Wildlife Service aluminum bands. Individuals deemed fit for transmitter 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 by Korschgen et al. (1996). Satellite transmitters weighed approximately 49 g and comprised <4% of the average body mass of birds deployed.

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).

Satellite telemetry

Telemetry data from PTTs were received via the Argos system of satellites. Data were archived, compiled, and filtered to remove redundant data and errant points using the Douglas Argos-Filter 2012 (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 adjusted 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 applied the hybrid filter of both the distance, angle, and rate (DAR) and minimum redundant distance (MRD) filters. The combination achieves the best of both filters and in practice has produced very clean data with few erroneous points (Douglas et al. 2012). Using DAF, we also chose to identify the best representative point per duty cycle for each animal to reduce redundant daily positional information. The DAF also generates estimates of the distance between successive points (as 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.

A custom script in Python 2.7 was developed so locations of each individual could be mapped in ArcGIS 10.2.2 (Environmental Systems Research Institute, Inc., Redlands, CA) with the DAF-filtered data. We chose to represent only one year's worth of data per life period per animal, in order to avoid biasing the dataset towards individuals with more years of data due to tag longevity or mortality. Based on evidence that the movement patterns of birds may be adversely affected in the first year following capture and implant of a satellite tag (S. G. Gilliland, unpublished data) and that tags seldom survived for an entire third year of deployment, we chose Year 2 data preferentially over Year 3 data, and Year 1 data if only one year of data existed. Only birds that transmitted >60 days after release were included, to reduce bias from birds that could have been negatively affected by transmitter implantation and handling.

Movement maps were created to show migratory movements to and from the wintering grounds. Period locational means for winter, breeding, and molting locations were used for these maps, calculated from all best locations per duty cycle available for those periods. Movement lines were created from all intermediate points between "book-end" periods such as winter and breeding, and show the link between these periods. Increasing line density where tracks were overlaid indicates areas used by multiple birds. Lines were straight-line paths between points and do not necessarily reflect the true path of the animal; the broadness and semitransparency of the lines used in these maps was intended to illustrate general migratory paths.

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 adehabitat HR version 0.4.13 (Calenge, 2006) in R version 3.1.1 (R Core Team 2014), removing 5% outliers. The first two weeks of data for every tag (the period immediately following release) was excluded from home range estimations, as were animals that transmitted for <30 days. Winter periods were identified for each individual based on arrival and departure from the wintering area.

Kernel density estimation of winter use

We produced kernel density maps that showed the broad-scale utilization distribution (0.95 isopleth) and core-use areas (0.50) of satellite transmitter-tagged Red-throated Loons, to determine potential wintering range overlap with proposed WEAs in the mid-Atlantic region. 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 is estimated to be 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 for a single composite KDE representing the utilization distribution of all animals. Fifty-four DAF-filtered locations were randomly selected from each individual's winter period. The winter period was defined for Year 1 data as 2 weeks after deployment until the individual departed the study area for spring migration and for Years 2 and 3 data as the individual's arrival date in the study area until the end of the transmitter's battery life. The number of locations randomly selected per animal (n = 54) was based on the 25^{th} percentile value of the distribution of the number of location data points available for each animals. The 25^{th} percentile value was chosen for minimization of weighting by individuals with larger numbers of available location data compared to individuals with fewer available location data due to transmitter failures or mortality events. A bootstrapping procedure was used to generate a mean utilization distribution from 100 runs of re-sampled points as described above. For maps of wintering and staging in this report, composite maps were developed consisting of all pooled, randomly sampled points generating a single composite utilization distribution.

Habitat selection

We examined third-order resource selection of Red-throated Loons 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). We were interested in determining core use areas within the home range, which is referred to as a third-order resource selection (Johnson 1980). 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 (°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), seafloor slope (°), and sediment grain type. We measured water depth and slope using the NOAA National Geophysical Data Center 3 arc-second Coastal Relief Model for the United States (NOAA 2014a). To estimate distance to 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). 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 Red-throated Loon habitat requirements. For dynamic variables with a temporal component, we relied on 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 used smoothed daily 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 0.054 degrees latitude and longitude. Sea surface salinity (SSS; psu) was estimated using the Hybrid Coordinate Ocean Model (HYCOM) produced by the National Ocean Partnership Program at a spatial scale of 1.5 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 all years combined and for each winter period. Development of models was exploratory, but, based on a priori knowledge of Red-throated Loon 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 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 SST to seasonal SST, (2) long-term to seasonal SSS, 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 < 0.60 and VIF values of < 2.3 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 was 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 in order 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

Forty-three Red-throated Loons were released with PTTs during the winters of 2012 (n = 17) and 2013 (n = 26), of which there were 24 females, 13 males, and six of unknown sex. Body mass of females ranged from 1,400-2,000 g and for males from 1,900-2,200 g. In each year, eight loons died within the immediate 14-day post-release period, which is the time period in which mortality can confidently be attributed to surgery (Mulcahy and Esler 1999). This corresponds with mortality rates of 41% for 2012 and 31% for the 2013 season.

Satellite telemetry

We observed local movements in the bays where individuals were captured and released, as well as larger scale movements in the near shore environment along the coast. More movement along the coast, between Delaware Bay and Pamlico Sound, was observed during the winter months among birds tagged in 2013 as compared to 2012 birds. The difference in loon movement between years is likely the result of more 2013 captures targeted in the mouths of Chesapeake Bay and Delaware Bay and offshore areas, as compared to the 2012 captures, which largely occurred in more interior locations of the bays.

Distances moved between duty cycles while in the study area were calculated for the winter period following deployment, which generally reflected movements during late winter and early spring, i.e., March, April, and May. These estimates ranged from 0 – 427 km for all animals combined (n = 22), and mean distance moved per animal ranged from 1.1 – 129 km. The resulting movement rates ranged from 0 – 15 km/hr moved for all tagged birds combined (n = 23) and the mean per animal ranged from 0.1 – 3.3 km/hr. Movement data was also available the winter after deployment for 16 individuals following their return from the breeding grounds, and generally reflected movements occurring in early winter, i.e., November, December and January. Distance moved between duty cycles for those birds combined ranged from 0.3 – 647km, and the mean distance moved per animal ranged from 8.5 – 118 km. The rate of distance moved for all birds combined during the second winter season ranged from 0.01 – 34 km/hr and the range in means for distance moved per individual bird was 0.4 – 7.3 km/hr.

Satellite tracking also showed the spring migration routes of 22 loons and the fall migration routes of 17 loons, information that was not previously available for this geographic region. Spring migration departure for the breeding grounds occurred between 23 March and 01 May (Figure 21-2). Most movements were along the coast, with the greatest offshore movements observed during the departure from the study area for spring migration. The majority of the birds followed the east coast of the Atlantic northward, and spent periods of time in Raritan Bay, NJ; Lower New York Harbor and the south shore of Long Island, NY; Narragansett Bay, RI; Nantucket Sound and Cape Cod Bay, MA; the Gulf of Maine, including the Maine coastline and Bay of Fundy; the Gulf of St. Lawrence, NB and QC and the St. Lawrence River, QC; James Bay, ON and QC; and Hudson Bay, ON, QC, MB, and NU. The southward fall migration included long layovers in Hudson Bay (4-8 weeks) before moving to the Great Lakes and the Gulf of St. Lawrence. Individuals that utilized the Great Lakes moved to Delaware Bay and down the coast to their wintering areas, while those that moved to the St. Lawrence followed the Atlantic coastline southward. Red-throated Loons in our sample returned to their wintering grounds in the mid-Atlantic study area between 15 November and 29 December (Figure 21-3).

Home ranges and kernel density estimation of winter use

Kernel density estimation maps were generated based on the highest quality daily location per duty cycle for Red-throated Loons with sufficient data (n = 22). Utilization distributions of Red-throated Loons included areas of: Delaware Bay and the Delaware Atlantic coastline; coastal Maryland and Virginia near Chincoteague Bay; Chesapeake Bay from Annapolis south to the mouth of the bay; and the Atlantic coastline from the Chesapeake Bay Bridge to the southern end of the Outer Banks of North Carolina (Figure 21-4). Core use areas within this UD were located in: Delaware Bay offshore of Fortescue Fish and Wildlife Management Area; Indian River Bay and coastal areas offshore of Rehoboth Beach; upper Chesapeake Bay near Annapolis, Tangier Sound; central Chesapeake Bay; Potomac and Rappahannock Rivers; southern Chesapeake Bay; coastal Atlantic from Bay Bridge south to Albemarle Sound; and mid- to eastern Pamlico Sound and offshore Outer Banks, North Carolina.

Individual home ranges of satellite-tagged Red-throated Loons following deployment ranged from 14.8 – 62,648 km^2 ($\bar{x}$ = 6,980 ± 14,132 km^2; n = 22) during their first winter period and from 23 – 12,491 km^2 ($\bar{x}$ = 3496 ± 4290 km^2; n = 16) for their second winter period. Individuals in the 2012 sample were captured in more interior bay locations and had smaller home ranges ($\bar{x}$ = 631 ± 1366 km^2) compared to birds captured in more coastal locations in 2013 ($\bar{x}$ = 11,741 ± 17,437 km^2).

Habitat selection

Across all three winter periods, little variation was observed between habitat characteristics associated with core use areas and available areas within the home range (Table 21-2). The greatest differences observed were in seasonal mean chlorophyll *a* concentrations ($\bar{x}$ = 7.73 ± 0.17 mg/m^3 in core use areas vs. $\bar{x}$ = 10.15 ± 0.17 mg/m^3 in available areas) and distance to shore ($\bar{x}$ = 5.81 ± 0.91 km in core use areas vs. $\bar{x}$ = 6.92 ± 0.16 km in available areas). Model results for all years combined showed a high amount of unexplained variation indicating a need to incorporate other potential habitat variables. Similarly, models examining resource selection during individual winter periods exhibited high unexplained variation for the 2011-2012 and 2013-2014 model periods. Models for the 2012-2013 winter period, however, performed well and the top model, which accounted for 0.97 of the Akaike weight, indicated a positive effect on habitat use related to increasing slope, sea surface salinity, and the compound effect of sea surface salinity and sea surface temperature, and a negative effect on use related to increasing sea surface temperature, distance to shore, and water depth; all other coefficients included in the top model had confidence intervals that included zero and were not considered reliable (Table 21-3 and Table 21-4). Among sediment types, core use areas in the top 2012-2013 model more frequently consisted of fine sand bottoms with grain sizes that ranged from 0.03-0.35 mm (Table 21-5). Considerable variation was observed in the mean habitat values associated with used and available locations between years (Table 21-6). In particular, seasonal and long-term chlorophyll *a* concentrations, water depth, and slope associated with Red-throated Loon core use areas were considerably greater during the 2012-2013 winter period compared to the 2013-2014 winter period. Conversely, mean values for long-term and seasonal sea surface temperatures and distance to shore were smaller for the 2012-2013 winter period compared to the 2013-2014 winter period.

Discussion

The heaviest use was observed around the mouth of the Chesapeake Bay, south along the coast to the Virginia/North Carolina border, and the central eastern portion of Pamlico Sound and coastal waters off Cape Hatteras National Seashore. Small areas in central and northern Chesapeake Bay, as well as areas along the Delaware coast and Delaware Bay, were also heavily used by loons in our sample. Red-throated Loon winter use near potential wind energy lease areas was greatest along the western edge of North Carolina off the Outer Banks; spring and fall migration movements also overlapped with that area. Migration trajectories through the New Jersey and Delaware lease blocks were heavier during the spring period than in fall. This seasonal difference was likely the result of more birds using an overland migration strategy in the fall, by pushing through the Great Lakes directly to Delaware Bay and Chesapeake Bay, whereas spring migration typically involved more movement along the Atlantic coast. Satellite tracking showed that loons in our sample arrived in the study area between mid-November and late December. 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 Red-throated Loons (1993 to 1997 mean: $\bar{x}$ = 57,679) wintering in the mid-Atlantic arrive between 15 October and 15 December (Forsell 1999). Departure from the study area for spring migration began in late March, and all birds had left by the beginning of May. In general, the greatest chance for interaction between Red-throated Loons in our sample and potential WEAs occurred during the migration periods rather than the winter period.

Winter habitat used by Red-throated Loons in Europe has been described as nearshore, sandy, shallow marine waters (Guse et al. 2009, O'Brien et al. 2008). However, limited information is available in the literature regarding measured habitat characteristics. Our model results examining the resource selection of Red-throated Loons in our study indicated that wintering birds predominantly used waters that were near-shore, shallow, and over flat, sandy substrate in the bays and coastal areas of the mid-Atlantic region. However, none of our tested models did an adequate job of explaining habitat use for

Red-throated Loons tracked in this study, indicating the need to explore additional habitat variables in future modeling efforts. Small pelagic fish species, such as American Sand Lance (*Ammodytes americanus*), are important food source for seabirds within the mid-Atlantic region and are likely a driving force for resource selection by Red-throated Loons. Spatial data on the distribution of small pelagic fisheries are limited, however, because these species are typically missed during traditional bottom trawl surveys (Greene et al. 2010). In the absence of such critical information, we were limited in our ability to determine a probability function for Red-throated Loon resource selection in the study area. The model for the winter period of 2012-2013 performed well and highlighted several important habitat characteristics, including water depth, distance to shore, chlorophyll *a* concentration, sea surface temperature, and salinity. Interpretation of the coefficients from this model and how they relate to Red-throated Loon habitat use should be conducted with caution, however, given the variation observed in these covariates between years. Quantifying the habitat characteristics within core use areas produced the most reliable information regarding Red-throated Loons use in the mid-Atlantic region. Loons in our sample used tidal rivers, bays, and ocean locations, and core use areas were generally 5-10 km from shore. Most ocean locations did not exceed 5 km from shore and were decidedly in the "nearshore" environment. Accordingly, water depth associated with use was shallow, with more than half the locations not exceeding 13 m. Among Red-throated Loons in the Baltic Sea, the greatest densities of birds were observed within an area with a water depth zone of 5-30 m (Skov et al. 2011). Similar to our findings, Warden (2010) found that the majority of Red-throated Loons taken as bycatch in mid-Atlantic waters occurred in waters less than 8 m deep (84%), while just 16 % occurred in 8-12 m deep water, and none were observed in water ≥ 12 m. Further, 43% of takes were in water that was < 8°C, 44% occurred in 8–12 °C water, and just 13 % were in water ≥ 12 °C. Our results indicated considerable use of waters that exceeded 12 °C; however, mean winter sea surface temperature associated with core use areas was below 12 °C.

Estimates of individual home range size varied widely, and were potentially affected by multiple factors. Capture locations in 2012 were limited to more interior locations of Chesapeake and Indian River Bays, and while these areas provide important habitat to wintering Red-throated Loons, data obtained from individuals captured at the sites may not fully represent the species' habitat use in more marine locations in the study area. Specifically, the mean home range size of loons captured near the mouths of Delaware and Chesapeake Bays and Pamlico Sound were on average larger compared to birds captured in more interior locations, suggesting that there may be large differences in movements and site fidelity among loon populations wintering in the region. A closer examination of home range size between winters for individuals that provided more than one season of data, however, shows great inter-annual variation in home range size. For example, one individual that was captured within Indian River Bay, DE in late February 2012 utilized a 110 km^2 home range between February 29 and April 8 that first year, and had a 5,708 km^2 home range between November 19 and February 4 the following winter. Many factors likely contributed to the observed variation in this metric, including:

(1) Differences in time of year. Specifically, first season winters occurred immediately after capture during the months of February, March and April, whereas second season winters included the

period of November to January, representing the period between an individual's return to the breeding ground and the transmitter battery reaching its maximum life span (≈ 1 year);

(2) Differences in length of time that individuals were tracked within a winter season, which was largely based on bird survival, number of quality data transmissions, and battery life; and

(3) Intra-and inter-annual variation in behavior, potentially associated with multiple factors, such as food resources, weather events, seasonal temperatures, age and condition of the bird, etc. The health of the bird, in particular, is an important consideration when considering home range size of the first winter period following surgical implantation of a satellite transmitter.

The range of mean rates of distance moved between duty cycles was greater for the second winter period compared to the winter period following deployment; however, it is difficult to determine whether differences in time of year and food availability better explain these differences than condition of the bird. 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 Red-throated Loon home range size on its wintering grounds in the mid-Atlantic region.

Our initial attempts to incorporate the utilization distributions of Red-throated Loons and habitat data associated with sampled locations into a resource selection function were not successful. However, data from 43 additional Red-throated Loons satellite-tagged during the winters of 2014 and 2015 will be available in early 2016, and are expected to improve the performance of the models. Model results can be used to predict probability of use of resource units, such as WEA lease blocks, based on the measured habitat characteristics of those units. Further, adjusting the ratio of the used to available points in the sampling scheme to Manly's (2002) recommended 2:1 design, and exploring other available habitat variables, may further improve the models (Manly et al. 2002). The ability to produce robust resource selection functions is critical to confidently identifying core use habitats within marine spatial planning areas.

The relatively large winter ranges of Red-throated Loons documented by our study increases the likelihood of displacement due to offshore WEAs compared to other seabirds with smaller ranges. Displacement of Red-throated Loons from several kilometers around wind farm footprints in Europe has been estimated to result in 89-94% reduction in loon densities at some locations (Petersen et al. 2006, Percival 2014), with no sustained evidence of habituation or return to the areas post-construction. Significant stressors already exist for this species on the wintering grounds, including exposure to pesticides and other contaminants, such as mercury and PCBs (Eriksson et al. 1992, Schmutz et al. 2009), oil spills, habitat degradation, and mortality from fishing nets (Zydelis et al. 2013). Red-throated Loons are particularly susceptible to mortality in the mid-Atlantic region via bycatch in gillnet fisheries. For example, of the 2,387 birds observed dead in gillnets in the mid-Atlantic region between February and April 1998, 68% were Red-throated Loons and 21% were Common Loons (*Gavia immer*; Forsell 1999). Another 825 dead Red-throated Loons were found washed ashore on beaches that winter. In total, Forsell (1999) estimated that this represented 1.2 to 2.4 % of the total number of fall migrating birds counted at Cape May earlier that season. Warden (2010) calculated that each year between 620 and 1,297 Red-throated Loons were taken as bycatch in commercial gillnet fisheries in the mid-Atlantic region, totaling an estimated 10,758 birds between 1996 and 2007. Additional mortalities on the wintering grounds, or indirect effects to wintering loons via displacement from important habitat areas, could have detrimental effects on the wintering population of Red-throated Loons in this region, and therefore it is critical that important foraging areas and movement pathways of loons and other vulnerable 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 results will be forthcoming in an anticipated manuscript publication in 2016.

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Figures and tables

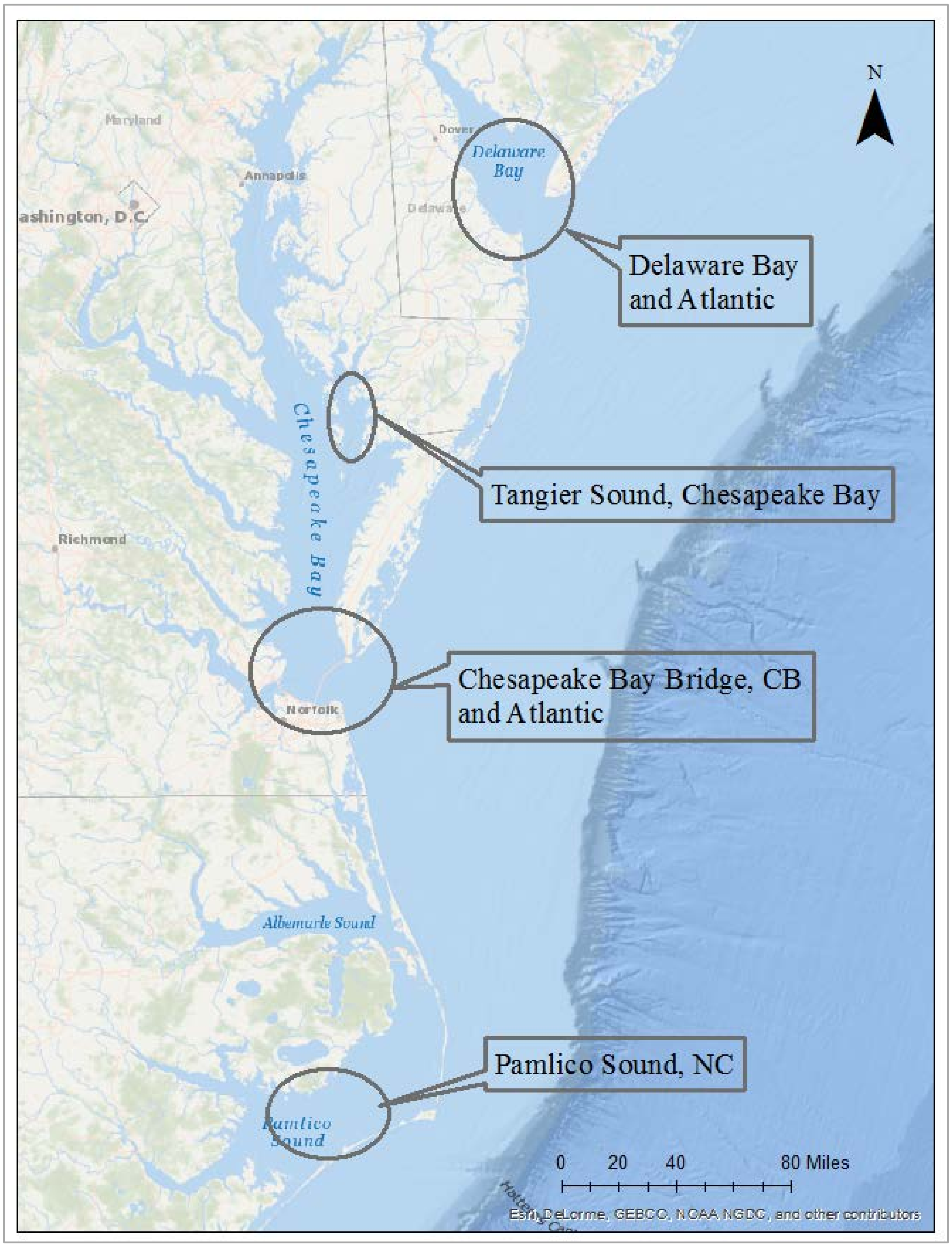

Figure 21-1. Red-throated Loon satellite-tracking study area. Capture efforts were concentrated in Delaware Bay (DE & NJ), Chesapeake Bay (MD & VA), and Pamlico Sound, NC.

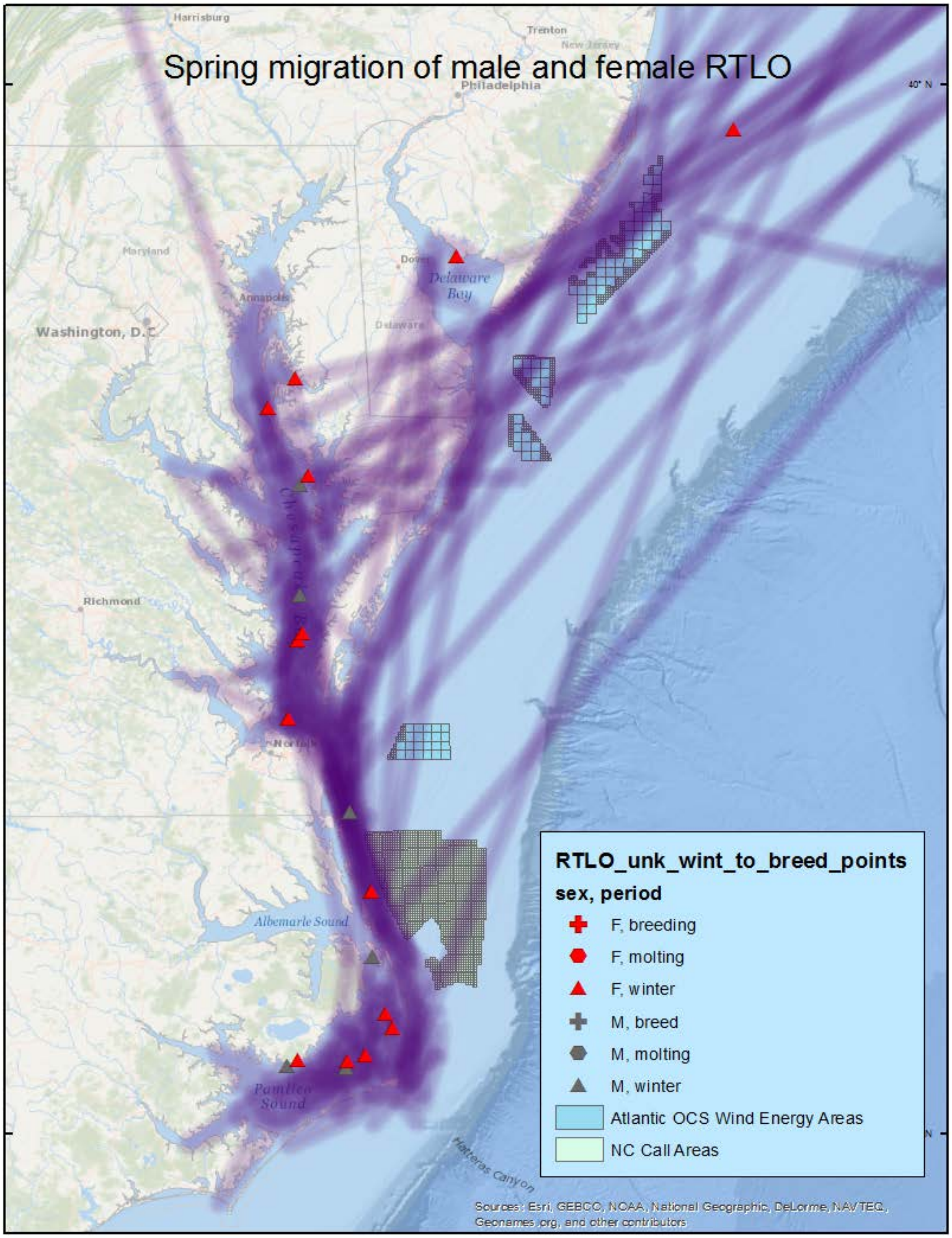

Figure 21-2. Spring migration movement map of Red-throated Loons departing the mid-Atlantic study area between late March and early May, 2012 – 2013. Points are locational means for each individual and life history period.

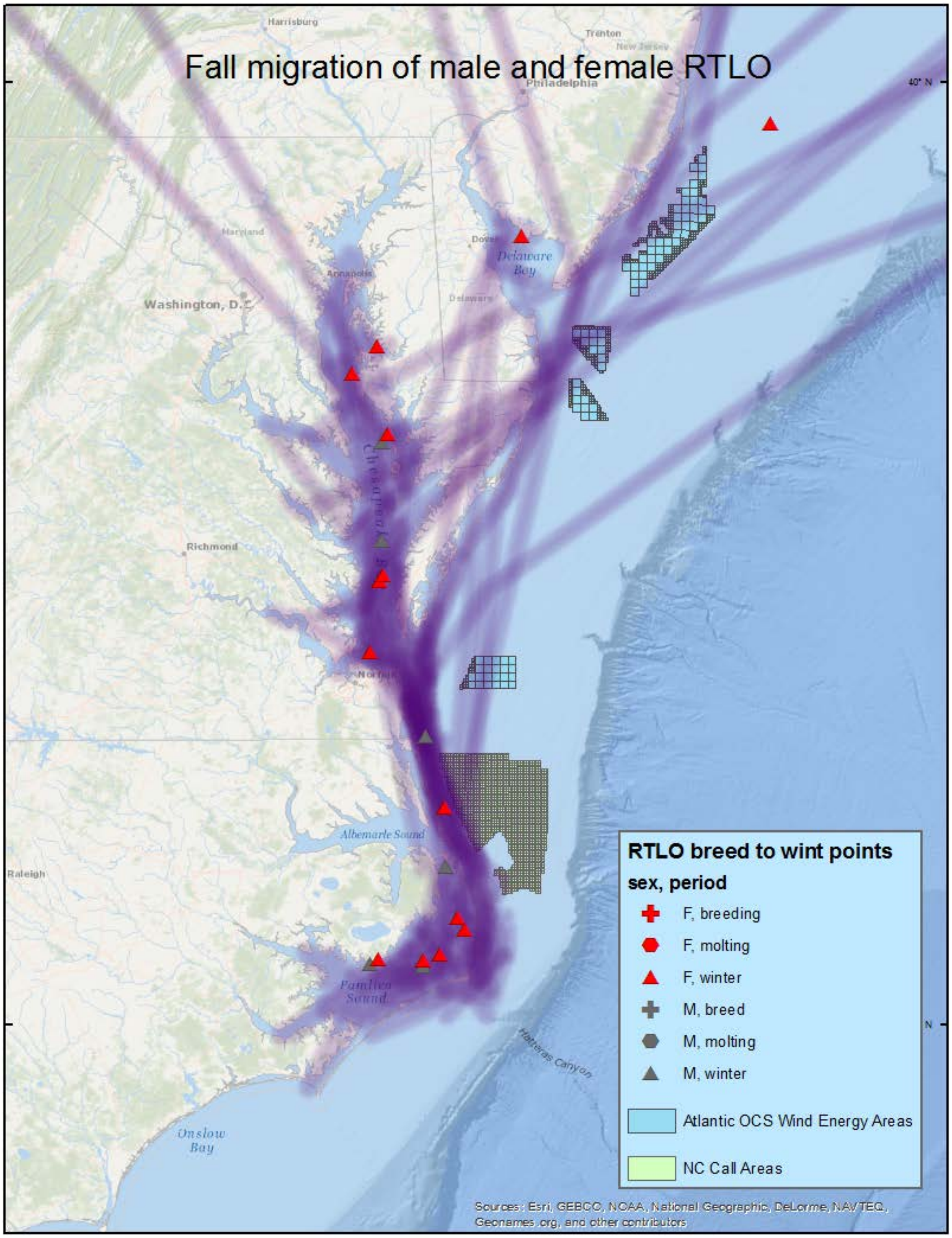

Figure 21-3. Fall migration movement maps of Red-throated Loons arriving in the mid-Atlantic study area between mid-November and late-December, 2012 – 2013. Points are locational means for each individual and life history period.

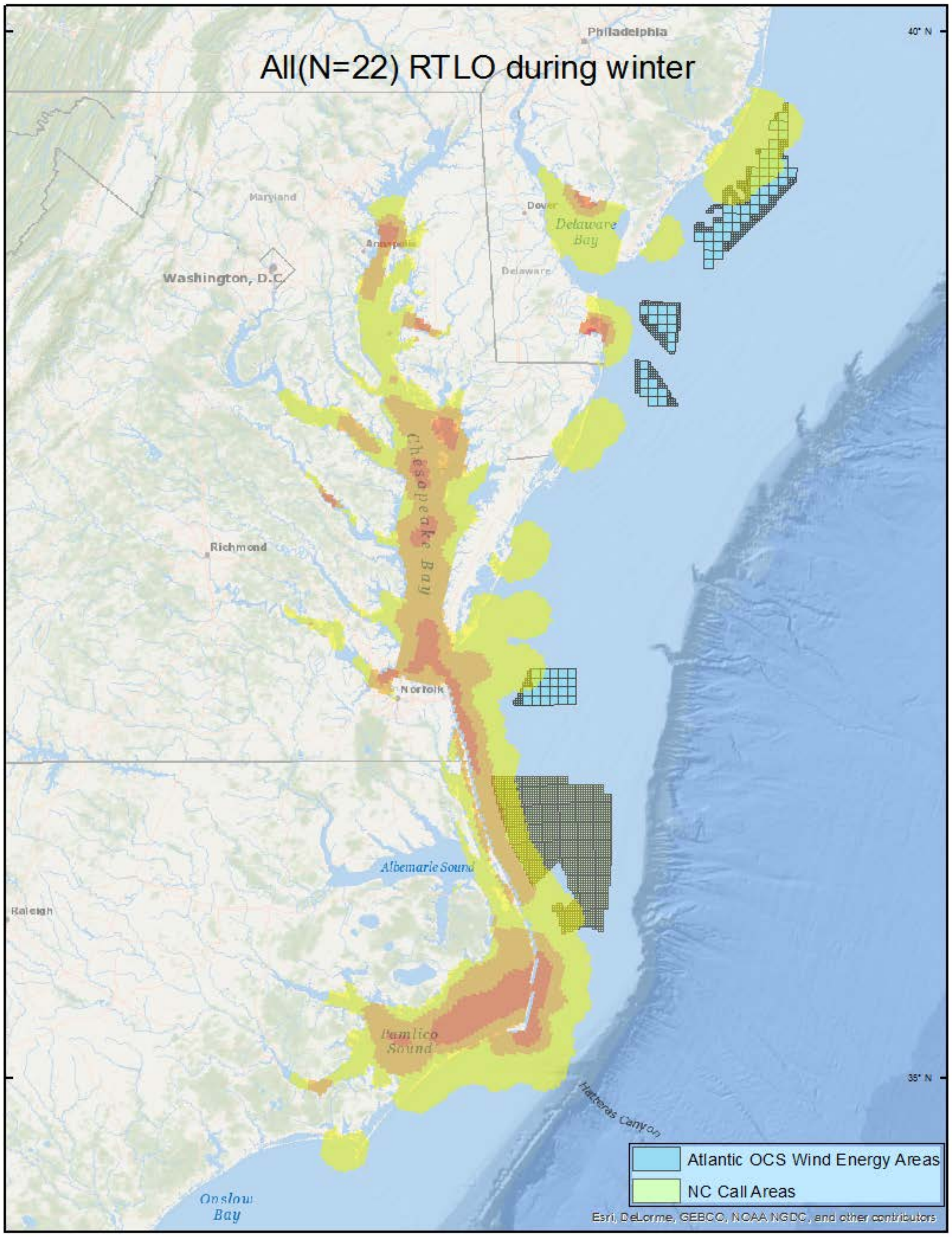

Figure 21-4. Winter use by Red-throated Loons of areas within the mid-Atlantic study area in relation to proposed offshore WEAs. Intensity of use ranges from lowest areas of use (yellow) to greatest areas of use (red).

Table 21-1. Number of Red-throated Loons implanted with satellite transmitters by capture location during the winters of 2012 and 2013.

Capture Location	2012	2013	*Total*
Chesapeake Bay, MD	11	—	***11***
Chesapeake Bay, VA	—	6	***6***
Delaware Bay, DE	1	9	***10***
Indian River Bay, DE	3	—	***3***
Pamlico Sound, NC	2	11	***13***
Total	***17***	***26***	***43***

Table 21-2. Range, mean ($\overline{x}$) and standard error (SE) of habitat variables at satellite-derived locations for Red-throated Loons in the core use area (0.50 isopleth) and for random points across the utilization distribution (available; 0.95 isopleth).

Habitat Variable	Available		Core Use	
	range	$\overline{x}$ ± SE	range	$\overline{x}$ ± SE
Long-term				
Chlorophyll *a* (mg/m^3) - 10 yr Mean	0.91 – 44.85	8.34 ± 0.13	0.92 – 44.85	8.56 ± 0.13
Sea Surface Temperature (°C) – 10 yr Mean	3.71 – 18.09	9.98 ± 0.11	3.78 – 18.86	9.89 ± 0.09
Sea Surface Salinity (psu) – 6 yr Mean	17.65 – 35.13	32.57 ± 0.04	17.65 – 35.35	32.67 ± 0.04
Physical				
Depth (m)	0.10 – 128.40	9.00 ± 0.20	0.10 – 127.00	8.68 ± 0.15
Slope (degrees)	<0.0001 – 3.86	0.16 ± 0.006	<0.0001 – 5.38	0.20 ± 0.007
Distance to Shore (km)	0.50 – 29.77	6.92 ± 0.16	0.50 – 40.52	5.81 ± 0.91
Short-term				
Seasonal Chlorophyll *a*(mg/m^3)	1.04 – 62.17	10.15 ± 0.22	1.08 – 95.04	7.73 ± 0.17
Seasonal Sea Surface Temperature (°C)	2.54 – 19.40	9.55 ± 0.11	0.00 - 20.46	9.76 ± 0.11
Seasonal Sea Surface Salinity (psu)	16.87 – 35.38	32.72 ± 0.05	17.39 – 35.56	32.82 ± 0.04

Table 21-3. Logistic regression model selection results examining the effects of slope (°), sediment grain size category (mm; sed), mean winter sea surface salinity (psu; sssw), mean winter sea surface temperature (°C; sstw), distance to shore (km; dist), depth (m; dep), and mean winter chlorophyll-a concentration (mg/m^3; chlorw) on winter habitat use versus availability by Red-throated Loons in the Mid-Atlantic region during the winter of 2012 - 2013. The table shows the variables included in the model, number of estimated parameters (K), model Akaike Information Criterion (AIC_c), differences between model AIC_c and the top model (ΔAIC_c), and AIC_c weights (w_i). Only models with ΔAIC_c of <7 are included in the table.

Model parameters	K	AIC_c	ΔAIC_c	w_i
slope+sed+sssw+sstw+(sstw*sssw)+dist+(sstw*dist)+dep^2+ (dep^2*dist)+chlorw+(sstw*chlorw)	14	787.456	0.000	0.973

Table 21-4. Coefficients (β) and 95% confidence intervals (lower and upper) of best-fit resource selection model for Red-throated Loons wintering in the mid-Atlantic region in 2012-2013.

Variable	β	Lower	Upper
Slope (°)	0.667	-0.078	1.56
sediment grain size (mm)			
0.00 - 0.03 clay/silt	0.21	-0.6	1.04
0.03 - 0.17 very fine sand	0.16	-0.29	0.61
0.17 - 0.35 fine sand	-0.15	-0.48	0.18
0.35 - 0.36 sand	0.39	-0.23	1.02
0.36 - 0.48 medium sand	-0.32	-0.83	0.2
seasonal sea surface salinity (psu)	0.74	0.61	0.88
seasonal sea surface temperature (°C)	-1.85	-2.21	-1.52
seasonal sea surface salinity*seasonal sea surface temperature	0.43	0.32	0.55
distance to shore (km)	-0.39	-0.51	-0.27
$depth^2$ (m)	0.02	0.003	0.03
$depth^2$ (m)*distance to shore (km)	0.001	0.0009	0.002
seasonal chlorophyll-*a* concentration (mg/m^3)	-0.88	-1.06	-0.72
seasonal sea surface temperature*seasonal chlorophyll-*a* concentration	-0.21	-0.26	-0.17

Table 21-5. Proportion of use of different sediment types at satellite-derived locations for Red-throated Loons in the core use area (0.50 isopleth) and for random points across the utilization distribution (available; 0.95 isopleth).

Grain Size (mm)	Sediment Type	Available		Core Use	
		n	% Use	n	% Use
0.00 - 0.03	Silt/Mud	157	10	287	13
0.03 - 0.17	Very Fine Sand	447	30	736	32
0.17 - 0.35	Find Sand	559	37	773	34
0.35 - 0.36	Sand	76	5	126	5
0.36 - 0.48	Medium Sand	116	8	136	6
0.48 +	Coarse Sand - Gravel	148	10	218	10

Table 21-6. Mean ($\overline{x}$) and standard error (SE) of habitat variables at satellite-derived locations for Red-throated Loons in the core use areas (used; 0.50 isopleth) and for random points across the utilization distribution (available; 0.95 isopleth) by winter period.

Habitat Variable	Point Type	n	2011 – 2012	n	2012 - 2013	n	2013 -2014
Long-term							
Chlorophyll *a* - 10 yr Mean (mg/m^3)	Used	111	17.40 ± 0.72	1068	8.31 ± 0.16	781	7.64 ± 0.11
	Available	403	9.34 ± 0.38	626	8.01 ± 0.21	356	7.80 ± 0.17
Sea Surface Temp – 10 yr Mean (°C)	Core Use	206	5.31 ± 0.25	1377	9.40 ± 0.12	795	11.93 ± 0.13
	Available	459	8.98 ± 0.17	707	10.34 ± 0.17	384	10.53 ± 0.19
Sea Surface Salinity – 6 yr Mean (psu)	Used	13	32.82 ± 0.47	681	32.73 ± 0.04	279	32.51± 0.05
	Available	226	32.53 ± 0.11	302	32.64 ± 0.06	184	32.51± 0.05
Physical							
Depth (m)	Used	209	5.20 ± 0.71	1366	9.70 ± 0.20	795	7.85 ± 0.17
	Available	452	10.39 ± 0.48	701	8.40 ± 0.29	382	8.48 ± 0.25
Slope (degrees)	Used	197	0.32 ± 0.03	1320	0.23 ± 0.01	722	0.12 ± 0.01
	Available	423	0.18 ± 0.02	653	0.16 ± 0.01	361	0.16 ± 0.01
Distance to Shore (km)	Used	215	2.92 ± 0.30	1392	4.75 ± 0.11	795	8.67 ± 0.15
	Available	457	6.40 ± 0.21	709	6.98 ± 0.15	385	7.44 ± 0.21
Short-term							
Seasonal Chlorophyll *a* (mg/m^3)	Used	0	—	1141	8.58 ± 0.26	785	6.49 ± 0.10
	Available	421	12.93 ± 0.58	655	10.36 ± 0.34	369	6.60 ± 0.14
Seasonal Sea Surface Temperature (°C)	Used	0	—	1377	9.93 ± 0.11	795	11.99 ± 0.16
	Available	459	7.08 ± 0.17	707	10.66 ± 0.16	384	10.48 ± 0.23
Seasonal Sea Surface Salinity (psu)	Used	0	—	681	32.69 ± 0.04	279	33.15 ± 0.07
	Available	226	32.56 ± 0.12	302	32.59 ± 0.06	184	33.13 ± 0.09