Research Article

Habitat Use and Selection of Black Scoters in Southern New England and Siting of Offshore Wind Energy Facilities

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ABSTRACT The southern New England continental shelf is an important region for black scoters (*Melanitta americana*) during winter and migratory staging periods and a priority area for developing offshore wind energy facilities. However, little is known about the migration phenology and habitat use of black scoters in this portion of their range and this information is necessary to assess potential risks to black scoters during the marine spatial planning process. In this regional black scoter study over 2 winters, we used satellite telemetry and spatial modeling techniques to estimate migratory timing and length of stay, quantify winter home range size and site fidelity between winters, examine key habitat characteristics associated with core-use areas, and map relative probabilities of use across a 3,800-km^2 marine spatial planning area for 2 proposed offshore renewable energy facilities. Black scoters spent nearly 5 months in southern New England, with wide variation among individuals in the size of winter utilization distributions (range 16–12,367 km^2). Approximately 50% of the tagged birds returned to southern New England during the subsequent winter and had variable fidelity to core-use areas occupied the previous winter. During both winters, black scoter core-use areas were located closer to shore, at shallower water depths, with coarser sediment grain size and higher probability of hard-bottom occurrence relative to available areas. Resource selection functions classified the majority of a nearshore 5-turbine, 34-km^2 renewable energy zone off Block Island as high probability of use by black scoters, whereas an offshore 200-turbine, 667-km^2 federal lease block zone was classified as low to medium-low probability of selection. Wind energy facilities, such as the Block Island site, constructed in relatively shallow (<20 m deep), nearshore habitats (<5 km) over hard-bottomed or coarse-sand substrate could displace some foraging black scoters wintering in this region, whereas the larger federal lease block zone located farther offshore is more likely to affect scoters dispersing among core-use areas and during migration between wintering and breeding grounds. © 2014 The Wildlife Society.

KEY WORDS black scoter, marine spatial planning, *Melanitta americana*, offshore wind energy, resource selection function, satellite telemetry, southern New England.

Factors responsible for the decline of over half of North America's sea duck populations are not well understood, although events during winter may affect populations (Tasker et al. 2000, Camphuysen et al. 2002, Oosterhuis and van Dijk 2002, Skerratt et al. 2005, Esler and Iverson 2010). Unfavorable habitat conditions on wintering grounds have been associated with mass sea duck mortality events (Camphuysen et al. 2002), decreased reproductive output (Oosterhuis and van Dijk 2002), and annual variability in

population indices (Petersen and Douglas 2004). During winter, sea ducks typically congregate at sites with high densities and biomass of benthic macroinvertebrate prey (Stott and Olson 1973, Guillemette et al. 1993), where they spend the majority of the diurnal period foraging (Goudie and Ankney 1986, Guillemette 1998, Fischer and Griffin 2000). Information on specific biotic and abiotic factors that influence the temporal and spatial distribution of sea ducks during winter (Bordage and Savard 1995, Savard et al. 1998, Zipkin et al. 2010, Silverman et al. 2013) is needed to understand how natural and anthropogenic changes to marine ecosystems may affect the spatial distribution of sea ducks and for conserving high-priority habitat (Dickson and Smith 2013). This is particularly true in the context of marine spatial planning because of the potential for offshore renewable energy development in North America.

Presently, no offshore wind facilities occur in the United States, although interactions between sea ducks and offshore wind facilities have been investigated in Western Europe since the early 1990s (Langston 2013). Sea ducks largely avoid colliding with wind turbines (Guillemette et al. 1998, 1999; Desholm and Kahlert 2005), but they are reluctant to forage near turbine arrays for at least 3 years following construction of offshore wind facilities (Guillemette et al. 1998; Petersen et al. 2006, 2007; Larsen and Guillemette 2007). Molluscivorous sea ducks that forage on sessile prey in shallow, subtidal areas may be particularly affected by disturbance-related habitat loss associated with offshore wind energy developments (Garthe and Hüppop 2004, Kaiser et al. 2006). Offshore wind energy facilities also may deflect sea ducks off their established migratory routes, creating barrier effects that may be energetically costly (Petersen et al. 2006, but see Masden et al. 2009). Therefore, investigating sea duck movements and habitat selection are important factors for developing plans that could minimize adverse effects of offshore wind energy facilities at key wintering sites (Drewitt and Langston 2006, Fox et al. 2006, Langston 2013).

One major marine spatial planning effort currently underway in southern New England is the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP), a federally-recognized, ecosystem-based management approach to zone offshore waters for multiple uses including commercial and recreational fisheries, cultural and historical resources, marine transportation and navigation, and development of offshore renewable energy facilities (RI Ocean SAMP 2012). As part of this effort, extensive ship-based and aerial surveys documented the distribution, abundance, and flight ecology of birds, including sea ducks, within Rhode Island's nearshore and offshore waters (Paton et al. 2010). These surveys were primarily designed to assess the spatial distribution and abundance of marine birds using nearshore and offshore areas, but provided little information about the timing, movement patterns, and specific habitat use of individual species of sea ducks wintering within this region, which could be useful for marine spatial planning within the RI Ocean SAMP area.

Baseline data on marine bird use of the RI Ocean SAMP is needed because 2 major offshore wind energy projects are currently planned for this area: a 5-turbine facility southeast of Block Island and a 200-turbine facility in Rhode Island Sound. To assess whether these proposed wind energy developments occurred in critical black scoter (*Melanitta americana*) habitat, we deployed satellite transmitters on black scoters to assess local movement patterns and habitat use. We analyzed location data transmitted by black scoters to 1) delineate arrival dates, departure dates, and overall length of stay during winter to assess when black scoters could interact with offshore wind energy developments in this region; 2) quantify the geographic extent of winter home ranges; 3) develop a population-level resource selection function model for black scoters that facilitates the identification of key habitat characteristics used during winter; and 4) map the relative probabilities of black scoter habitat use throughout the RI Ocean SAMP study area to inform marine spatial planning.

STUDY AREA

We conducted fieldwork in the southern New England continental shelf region from southern New York Bight to Cape Cod Bay (40°N–42°N; Fig. 1). The region's complex coastline includes the Cape Cod peninsula and an archipelago of geologically diverse offshore islands. This region is recognized as a particularly important area for black scoters during winter and migratory staging periods (Zipkin et al. 2010, Silverman et al. 2013). Subtidal sediments ranged from clay to gravel, with finer substrates common within estuarine habitats and sand predominating throughout nearshore areas (Theroux and Wigley 1998). Scattered cobble to boulder-sized rocks formed patchily distributed reefs, primarily from eastern Long Island to Cape Cod (Steimle and Zetlin 2000). Fresh water drains into the shelf from a mosaic of vertically homogeneous to moderately stratified bays, sounds, and estuaries including Cape Cod Bay, Buzzard's Bay, Nantucket Sound, Narragansett Bay, and Long Island Sound. Tidal cycles were semi-diurnal and varied from 0.6 m to 1.3 m along the coast. The region had winter temperatures of inner-shelf surface waters that range from 2 to 3°C (Bumpus 1973). The RI Ocean SAMP marine spatial planning zone was located centrally within the study area and encompassed approximately 3,800 km² of state and federal waters within Block Island Sound, Rhode Island Sound, and the inner continental shelf (Fig. 1). Two potential areas for offshore renewable energy development have been identified within the RI Ocean SAMP area: an approximately 34-km² nearshore Renewable Energy Zone within Rhode Island state waters southeast of Block Island, where a 5-turbine, 30-MW wind energy facility is in the final planning stages, and a larger, 667-km² offshore Area of Mutual Interest (AMI) located in federal waters between Rhode Island and Massachusetts along the southeastern boundary of the RI Ocean SAMP area, where the federal lease block bidding process was recently initiated for a 200-turbine, 1,000 MW offshore wind energy facility (RI Ocean SAMP 2012; Fig. 1).

METHODS

Satellite Telemetry

We used satellite telemetry to track the locations of black scoters along the southern New England continental shelf. We instrumented black scoters with satellite tags during May 2010 in Chaleur Bay, New Brunswick, Canada (New Brunswick scoters) and during December 2010 in Rhode Island, USA (Rhode Island scoters). We captured black scoters at both locations using floating mist nets and decoys (Brodeur et al. 2008). We determined age and sex of birds using bursal depth and plumage characteristics (Iverson et al. 2003). Following procedures described by Korschgen et al. (1996), we had a qualified veterinarian surgically implant a 40-g pressure-proofed platform transmitting
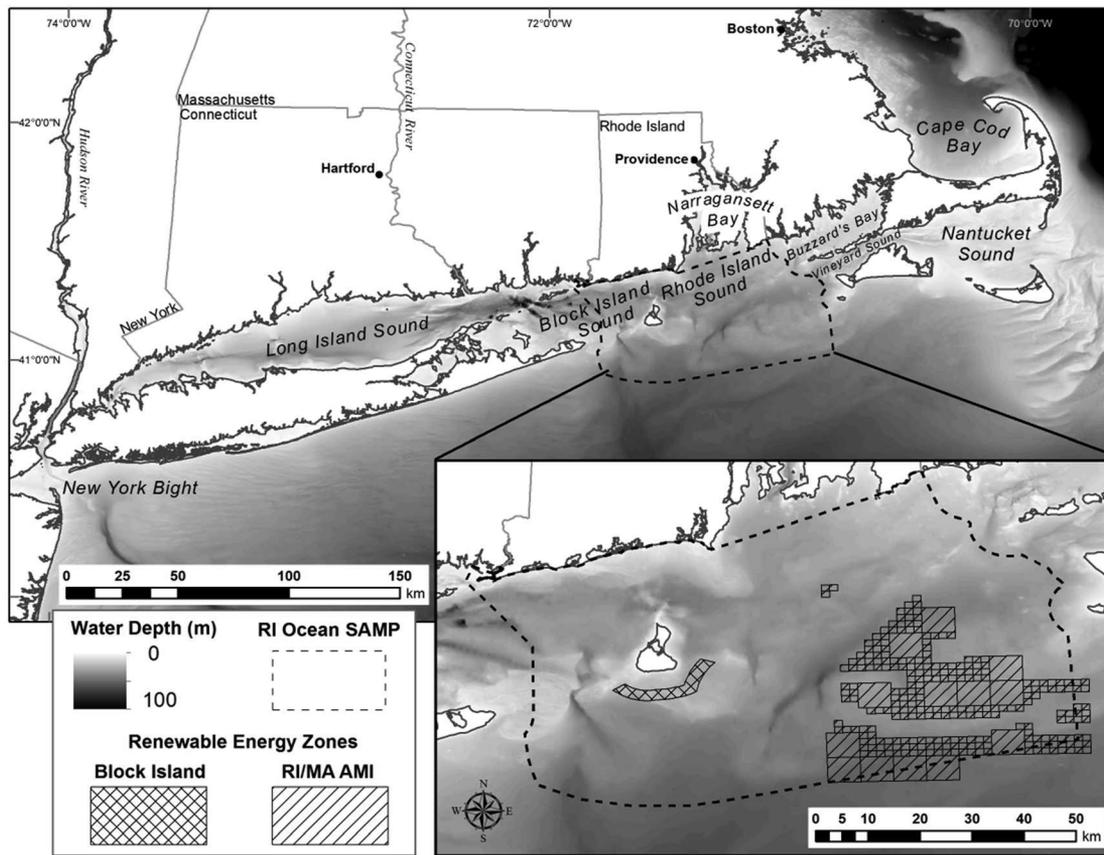
Figure 1. Bathymetry of the southern New England continental shelf study area and the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP) marine spatial planning area (dashed line), with potential sites for offshore wind facilities delineated for the Block Island (cross-hatching) and Rhode Island/Massachusetts Area of Mutual Interest [RI/MA AMI; diagonal-hatching] Renewable Area Zones.

terminal satellite transmitter (PTT; PTT-100, Microwave Telemetry, Columbia, MD) with a percutaneous antenna into the abdominal cavity of each black scoter. Satellite transmitters comprised <4% of the average body mass of birds instrumented. We released birds at or near the capture site ≤24 hours after initial capture (Olsen et al. 2010).

We instrumented 57 black scoters from 1 to 10 May 2010 in Chaleur Bay, New Brunswick, of which 23 spent at least 1 winter in the southern New England study area. Various duty cycles have been used in satellite telemetry studies of sea ducks, in part because of differences in study objectives (Merkel et al. 2006, Phillips and Powell 2006, De La Cruz et al. 2009). The satellite transmitters we deployed in Canada were programmed to a single duty cycle of 2 hours on and 72 hours off, which allowed for transmission of location data for approximately 2.5 years. In Rhode Island, we deployed 18 satellite tags on black scoters (2 after second year [ASY] F, 3 ASY M, 2 second year [SY] F, 3 hatch year [HY] F, 8 HY M) in early December 2010, using a 2-period duty cycle designed to collect accurate, daily location data during first winter of deployment and semi-weekly location data during the following breeding season and subsequent winter. During period 1 (first winter) the duty cycle was 4 hours on and 24 hours off for 116 cycles. The period 2 (breeding season and subsequent winter) duty cycle was 4 hours on, 96 hours off, and lasted through the end of battery life (approx. 1–1.25 yrs).

The transmitters we deployed in New Brunswick and Rhode Island were programmed to collect location data on different duty cycles and obtained different proportions of locations within each estimated accuracy class. The accuracy of fixes increases with the number of transmissions received by polar-orbiting satellites, and a positive relationship exists with both the latitude and duration of the on-duty cycle (Collecte Localisation Satellites 2012). In southern New England, fixes from satellite transmitters operating on a 4-hour duty cycle had 20% more locations classified as accurate to within 500 m compared to location data from transmitters operating on a 2-hour duty cycle. We were interested in obtaining more accurate locations during the winter to better understand fine-scale movement patterns of black scoters in southern New England, thus a 4-hour on, multi-season duty cycle was more desirable to meet this objective relative to a 2-hour on, 1-season duty cycle. The shorter 2-hour on-cycle provides less accurate locations but longer battery life and allowed us to assess inter-annual site fidelity to wintering grounds.

To reduce any potential bias associated with surgery, we excluded from subsequent analyses all location data collected

within 14 days of initial deployment (Esler et al. 2000). The start date of the study period for Rhode Island instrumented black scoters was 20–25 December 2010 (median date: 21 Dec 2010). The PTTs switched to the period 2 duty cycle between 28 April and 2 May 2011 (median date: 29 Apr 2011). All methods were approved by the University of Rhode Island Institutional Animal Care and Use Committee (Protocol # AN10-08-004).

Location Data

We used Argos instruments flown aboard polar-orbiting satellites to receive messages transmitted by PTTs. Argos Processing Centers calculated location estimates using a least squares algorithm to measure the Doppler effect on transmission frequencies and reported an estimated accuracy class associated with each location (Collecte Localisation Satellites 2012). For location classes 3, 2, 1, and 0, Collecte Localisation Satellites America categorized accuracy estimates into 4 distance intervals of $<250\,m$, 250 to $<500\,m$, 500 to $<1,500\,m$, and $>1,500\,m$, respectively (Collecte Localisation Satellites 2012, but see Douglas et al. 2012). Accuracy was not provided for location class A (3 messages received by satellite), location class B (2 messages), or location class Z (invalid location) and we used few of these locations for subsequent analyses (see Results section).

We used the Douglas-Argos Filter (Douglas Argos-Filter 2012) to remove implausible locations using minimum redundant distance and distance-angle-rate tests between consecutive location points. We retained for subsequent analyses only the highest quality location per duty cycle using the following criteria in rank order: 1) Argos location class, 2) residual error on the frequency calculation, 3) number of messages received, and 4) transmitter oscillator frequency drift between 2 satellite passes. We managed, displayed, and analyzed spatial data using ArcGIS 10.0 (Environmental Systems Research Institute, Inc., Redlands, CA) in the Alber's Equal Area Conic projection. We used SAS 9.2 (SAS Institute, Inc., Cary, NC) for all statistical analyses.

Phenology and Length of Stay

To assess when black scoters might be vulnerable to wind turbines if they were constructed in offshore areas of southern Rhode Island, we calculated phenology and length of stay of black scoters using the following criteria described by De La Cruz et al. (2009). We defined the arrival date to the study area as the median date between the date of the previous location outside of the study area and the first location within the study area during fall migration. We defined departure date from the study area as the median date between the date of the last location within the study area and the following location outside of the study area during spring migration. We estimated length of stay as the number of days between the fall arrival date and spring departure date plus 1 day, as birds could have been present in the study area on the arrival date and/or the departure date. For birds that made forays outside of the study area during the wintering period, we calculated arrival dates, departure dates, and length of stay using the above criteria, and determined their

total length of stay within the study area by subtracting their length of stay during forays outside of the study area from their length of stay within the study area.

Because these data were non-normally distributed, we used Wilcoxon rank-sum tests to compare, for the 2010–2011 winter period: fall arrival dates, spring departure dates, and overall length of stay in the study area for New Brunswick scoters by sex. We pooled age cohorts, as we found no difference between ASY and SY cohorts in fall arrival dates, spring departure dates, and overall length of stay. For birds in our sample that wintered in the study area during both the 2010–2011 and 2011–2012 winter periods, we used Wilcoxon signed-rank tests to compare fall arrival dates, spring departure dates, and length of stay between winter periods.

Winter Utilization Distributions

To assess the overlap in the utilization distributions of black scoters and proposed offshore wind energy facilities in our RI SAMP study area, we first defined the winter period as the date when birds arrived in the study area until 31 April, as survey data indicate that black scoters were largely absent from southern New England by May (Veit and Petersen 1993, Paton et al. 2010). For each winter period (2010–2011 and 2011–2012), we generated individual and composite (population-level) kernel-based utilization distributions (0.95 isopleth) and core-use areas (0.50 isopleth) for black scoters that spent at least 50% of the winter period within the study area. We randomly selected 40 locations within the study area from each wintering black scoter to calculate individual kernel density estimates and pooled these locations across individuals to generate a composite kernel density estimate for each winter period. We generated all kernel density estimates, 0.95 utilization distributions, and 0.50 core-use areas with the software Geospatial Modeling Environment (Geospatial Modeling Environment Version 0.5.3 Beta, http://www.spatialecology.com/gme, accessed 1 May 2012) using a Gaussian kernel and likelihood cross-validation bandwidth estimator. Simulations by Horne and Garton (2006) showed that likelihood cross-validation provided better fit with reduced variability than least squares cross-validation when estimating utilization distributions from sample sizes <50. We used the National Oceanic and Atmospheric Administration's (NOAA) Medium Resolution Digital Vector Shoreline data (1:70,000; NOAA 2012a) to delineate the landward boundary for each utilization distribution and then calculated the total area of 0.50 core-use areas and 0.95 utilization distributions in km^2. For utilization distributions with 2 or more disjoint core-use areas, we calculated the distance between each core-use area as a Euclidean distance (km) between centroids.

For the 2010–2011 winter period, we used Wilcoxon rank-sum tests to compare the total area of utilization distributions and core-use areas by sex for New Brunswick scoters. For black scoters that wintered in the study area during both 2010–2011 and 2011–2012, we were interested if birds exhibited site fidelity to core use areas. We compared total area of utilization distributions and core-use areas between

winter periods using paired *t*-tests and quantified winter site fidelity as the percent area that individual utilization distributions overlapped between winter periods. For each winter period, we estimated overall area (km^2) of the composite utilization distribution and core-use areas in relation to hydrographic features (U.S. Geological Survey 2002) throughout the study area.

Habitat Use and Selection

We investigated habitat use of satellite-tagged black scoters to assess preferences and make recommendations on habitats that should be avoided for wind energy development to minimize impacts to black scoters. We used the composite kernel density estimates to examine habitat use versus availability during each winter period. We analyzed habitat use over a 24-hour period because comparisons of day versus night locations detected little difference in distance to shore values relative to estimated accuracy of the location data (Loring 2012). All habitat data that we used were in raster format and resampled to a standardized cell size of 250 m^2. We created a distance to shore grid by calculating the Euclidian distance (m) of each cell to the closest segment of the NOAA Medium Resolution Digital Vector Shoreline (1:70,000). We obtained bathymetry data from the NOAA National Geophysical Data Center 3 arc-second (approx. 90 m) U.S. Coastal Relief Model (NOAA 2012*a*). We used predictive models of mean grain size (phi scale) for the study area developed at approximately 370-m resolution (Poti et al. 2012). To estimate relative probability of hard bottom occurrence throughout the study area, we extracted from NOAA Electronic Navigational Charts (NOAA 2012*b*) seabed area vector datasets, all rock or boulder points ($n = 2,182$) throughout the study area and created a kernel-based probabilistic model of hard-bottom occurrence using a likelihood cross-validation bandwidth estimator.

We used the 2010–2011 and 2011–2012 composite home ranges to examine third-order resource selection (Johnson 1980), comparing habitat characteristics of core-use areas to habitat characteristics available throughout the utilization distributions for each winter period (sampling protocol-A; Manly 2002). We randomly sampled habitat variables at 25% of resource units within the utilization distributions and the core-use areas, with a minimum distance of 1 km between resource units to reduce spatial autocorrelation.

We computed a Pearson product-moment correlation matrix to quantify the correlation between pairs of habitat variables (distance to shore, water depth, grain size, and hard bottom probability) and calculated variance inflation factors (VIF) to assess multicollinearity of covariates. Within samples from each winter, pair-wise correlation among habitat variables did not exceed 0.70 and values of VIF were <1.5, so we retained all variables in the modeling step. We used logistic regression to estimate the parameters for exponential models, which were resource selection functions (RSF; Manly 2002).

We selected the best of 12 a priori candidate models for each winter (2010–2011, 2011–2012) using Akaike's Information Criterion adjusted for small sample size (AIC$_c$). We ranked models using AIC$_c$ differences (ΔAIC$_c$) and calculated AIC$_c$ weights (w_i) to evaluate the relative likelihood of each candidate model (Burnham and Anderson 2002). Competitive models were ≤ 2.0 ΔAIC$_c$ units from the top-ranked model and did not include any uninformative parameters (85% confidence intervals that overlapped zero; Arnold 2010). We evaluated the ability of the RSFs to predict use using each winter's top-ranked RSF based on both parametric (Johnson et al. 2006) and non-parametric (Boyce et al. 2002) k-fold cross-validation methods. We followed Huberty's (1994) rule of thumb to partition the sample of used resource units into 3 k-folds with 63% of the data being used for model training and 37% for validation, and partitioned available resource units into 10 quantile bins estimated from predicted RSF scores. With each technique, strong predictive ability of the RSF to reflect use is associated with high correlation (r or r_s) between the frequency of withheld testing data and either the expected proportion of use from the RSF model (Johnson et al. 2006) or the ranked RSF availability bins (Boyce et al. 2002). For each winter, the distribution of the cross-validation data did not meet the assumptions of the linear regression model, so we report only the validation results from the non-parametric technique.

Using the RSF estimated from the top-ranked exponential model of each winter period, we predicted the relative probabilities of black scoter habitat selection throughout the RI Ocean SAMP study area. We classified relative probability values into 25% quantiles (low [0–25%], medium-low [>25–50%], medium-high [>50–75%], and high [>75–100%]). We quantified the total area (km^2) by quantile class for each winter period and calculated percentages of spatial overlap among quantile classes between the 2 winter periods. We assumed that areas with a high probability of selection were high quality habitats that regulators should consider avoiding when planning the placement of offshore wind energy developments.

RESULTS

Survival and Location Data

Thirty-nine New Brunswick scoters transmitted data throughout the entire 2010–2011 winter period, of which 23 spent the majority of at least 1 winter within the study area (22 birds during 2010–2011 and 8 birds during 2011–2012, of which 1, a ASY F, was detected in our study area only this second winter; Tables 1 and S1, available online at www. onlinelibrary.wiley.com). Of the 18 Rhode Island scoters instrumented in December 2010, 9 (1 ASY M, 8 HY) died within 2–3 weeks of instrumentation and 3 transmitters went offline on live birds. The winter of 2010–2011 in southern New England was unusually cold, with record-breaking snowfall from several large storms that occurred within the month (NOAA 2012*c*) following the release of Rhode Island-tagged scoters that likely contributed to the increased mortality rate of HY scoters during this study. Six Rhode Island scoters transmitted data during the entire 2010–2011 winter period and all of these birds wintered within the study

Table 1. Number of satellite-tagged black scoters, listed by age cohort (hatching year [HY], second-year [SY], and after-second-year [ASY]) and sex (unknown [U], female [F], male [M]), tracked in the southern New England continental shelf study area during the winters of 2010–2011 and 2011–2012. We captured scoters in May 2010 in New Brunswick, Canada and in December 2010 in Rhode Island, USA.

Capture site	Winter	HY U	SY F	ASY M	ASY F
New Brunswick	2010–2011		3	15	4
	2011–2012			2	6
Rhode Island	2010–2011	2	2	1	1
	2011–2012				1

Figure 2. Latitude (°N) of locations for 22 black scoters that were satellite tagged with uniquely numbered Platform Transmitting Terminals (PTTs) during May 2010 in New Brunswick, Canada and spent the majority of the 2010–2011 wintering period (fall arrival to spring departure) within the southern New England continental shelf study area. Eleven birds remained within the study area throughout the 2010–2011 wintering period (A, top) and 11 birds made forays outside of the study area during the 2010–2011 wintering period (B, bottom).

area. Only 1 Rhode Island scoter (ASY F) transmitted data throughout the subsequent 2011–2012 winter period (Table S2, available online at www.onlinelibrary.wiley.com).

Phenology and Length of Stay

For New Brunswick scoters, median 2010 fall arrival date to the study area was 25 October (range 7 Oct–20 Nov, $n = 22$) and median 2011 spring departure date was 2 April (range 4 Mar–24 May, $n = 22$). During the 2010–2011 winter period, median dates of fall arrival to the study area and spring departure from the study area were earlier for New Brunswick scoter males compared to females by 10 days ($Z = 1.77$, $P = 0.077$) and 9 days ($Z = 2.231$, $P = 0.026$), respectively. For the 8 New Brunswick scoters that wintered in the study area during both 2010–2011 and 2011–2012, we did not detect differences in fall arrival dates ($S = -5$, $P = 0.547$) or spring departure dates ($S = 8$, $P = 0.219$) between winter periods. Mean ($\pm$SE) length of stay within the study area by New Brunswick scoters was 147 ($\pm$4) days during 2010–2011 and did not differ between sexes ($Z = 1.34$, $P = 0.180$). Length of stay by New Brunswick scoters that wintered in the study area during both 2010–2011 and 2011–2012 was not different between years ($P = 0.313$, $n = 8$).

During the 2010–2011 winter period, 11 New Brunswick scoters remained within the study area after their arrival to southern New England (Fig. 2A) and 11 New Brunswick scoters ranged outside of the study area for a mean ($\pm$SE) foray of 18 days ($\pm$5; range 4–51 days; Fig. 2B). All of the Rhode Island scoters remained within the study area during the 2010–2011 winter period, except 1 ASY male that made 4 separate 1-day trips to the New Jersey-Delaware coast from 16 January to 29 March 2011. All 10 birds (9 banded in New Brunswick and 1 from Rhode Island) that wintered in the study area during 2011–2012 remained throughout the winter period, except 1 ASY male who spent 23 February to 23 March in Delaware Bay prior to spring migration (Fig. 3).

Utilization Distributions

Individual.—Accuracy ratings of best-daily locations that we used to generate winter utilization distributions ranged from location class 3 to B, with most locations classified as ≥ 1 (Table 2). The percentage of locations within each estimated accuracy class varied by tagging cohort with different duty cycles during winter. During the winter of 2010–2011, 72% of locations transmitted by Rhode Island
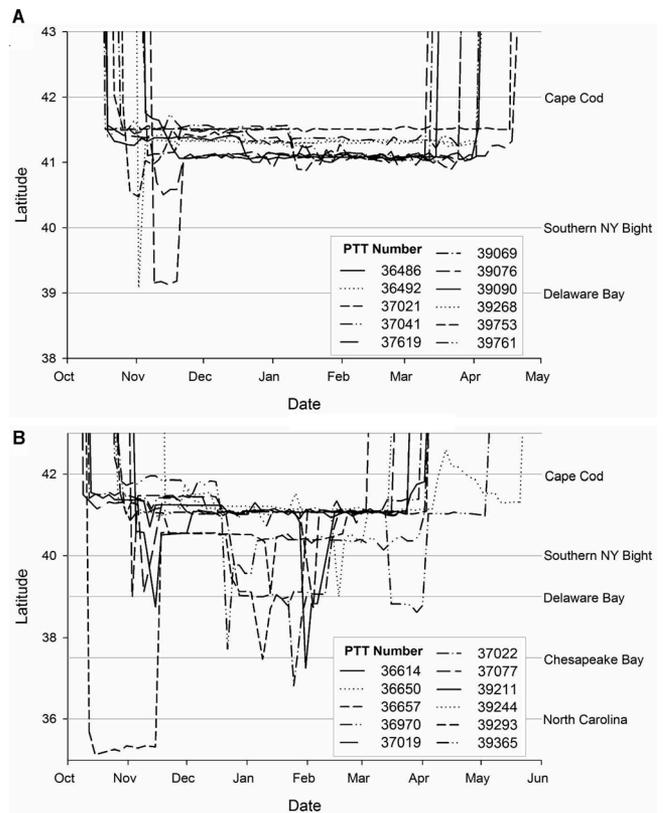
scoters were classified as location class 3 or 2 (estimated accuracy ≤ 500 m), whereas 50% of locations were classified as location class 3 or 2 for New Brunswick scoters (Table 2).

Overall size of winter utilization distributions varied widely among individuals (range 16–12,367 km^2). However, we
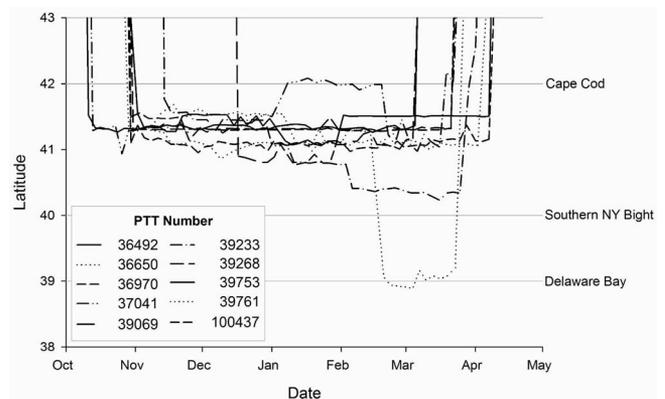

Figure 3. Latitude (°N) of locations for 10 black scoters that were satellite tagged with uniquely numbered Platform Transmitting Terminals (PTTs) and spent the majority of the 2011–2012 wintering period (fall arrival to spring departure) within the southern New England continental shelf study area.

Table 2. Location class and frequency count of randomly selected ($n = 40$ per individual) locations used to generate utilization distributions of individual black scoters in the southern New England continental shelf study area during the winters of 2010–2011 and 2011–2012. Black scoters are grouped by location of satellite tag deployment: Chaleur Bay, New Brunswick, Canada and Rhode Island, USA. During winter, the duty cycle of transmitters was 2 hours on and 72 hours off for New Brunswick scoters, and 4 hours on and 24 hours off for Rhode Island scoters.

	New Brunswick		Rhode Island	
Location class[a]	Frequency	Percent	Frequency	Percent
3	234	20	88	32
2	345	29	101	37
1	283	24	63	23
0	230	19	13	5
A	63	5	5	2
B	32	3	2	1

[a] Locations classified by the following accuracy intervals (m): 3 (<250), 2 (250 to <500), 1 (500 to <1,500), 0 (>1,500; Collecte Localisation Satellites 2012, but see Douglas et al. 2012). Accuracy is not provided for location class A (3 messages received by satellite) or B (2 messages received by satellite).

found no differences between sexes when comparing the total area of utilization distributions ($Z = 0.000$, $P = 1.00$) or core-use areas ($Z = -0.212$, $P = 0.832$) of New Brunswick scoters in 2010–2011. We also did not find differences by winter period in the overall area of utilization distributions ($t_8 = -1.125$, $P = 0.293$) or core-use areas ($t_8 = -1.036$, $P = 0.331$) for 9 birds that wintered in the study area during both 2010–2011 and 2011–2012 (Table S3, available online at www.onlinelibrary.wiley.com).

Individual black scoters ranged widely throughout the study area within each winter period and showed moderate site fidelity between winter periods. During each winter period, individual black scoters occupied 1–3 disjoint core-use areas. In both winter periods, 50% of the birds occupied multiple core-use areas. For birds with 2 or more core-use areas, mean distance between centroids was 113 km (± 20) in 2010–2011 and 109 km (± 13) in 2011–2012. For the 9 black scoters that wintered in the study area during both 2010–2011 and 2011–2012, spatial overlap between winter periods averaged 32% (± 10) for core-use areas and 24% (± 6) for utilization distributions (Table S3, available online at www.onlinelibrary.wiley.com). Although individual black scoters ranged widely and often occupied several core-use areas, the locations used by black scoters in the study area were relatively consistent and supported estimating composite utilization distributions for this population of black scoters during winter.

Composite.—During the 2010–2011 winter period, the overall extent of the winter composite ($n = 28$ pooled individuals) utilization distribution was 5,591 km², with core-use areas totaling 590 km² (Fig. 4A). For the 10 birds that wintered in the study area during 2011–2012, the overall extent of the composite utilization distribution was 5,913 km², with core-use areas totaling 759 km² (Fig. 4B). In both 2010–2011 and 2011–2012, over 50% of the total extent (km²) of composite core-use areas was within or adjacent to the RI Ocean SAMP boundaries, in waters of the inner continental shelf and Block Island Sound (Table S4, available online at www.onlinelibrary.wiley.com).
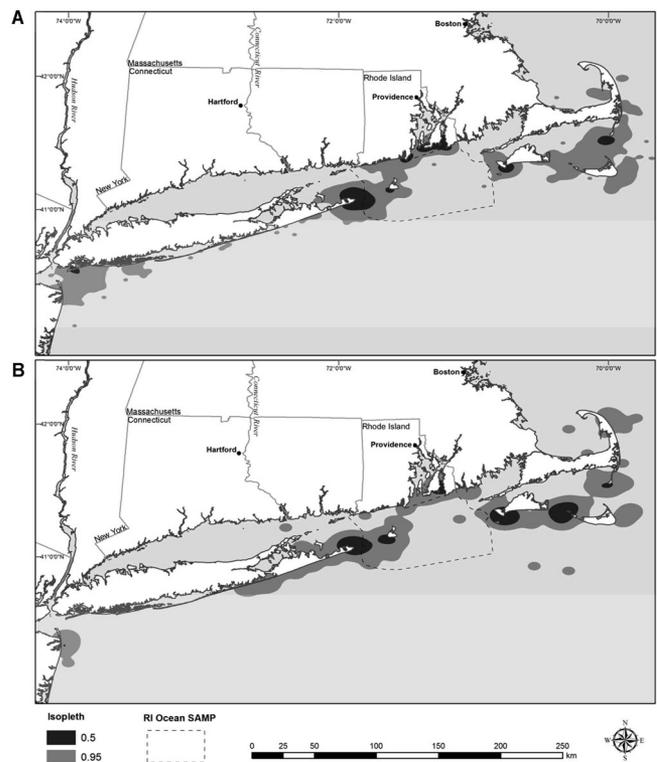

Figure 4. Composite kernel-based winter utilization distribution (light gray, 95% isopleth) and core-use areas (dark gray, 50% isopleth) of 28 satellite-tagged black scoters during 2010–2011 (A, top) and 10 black scoters during 2011–2012 (B, bottom) within the southern New England continental shelf study area, in relation to the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP) marine spatial planning area (dashed line).

Resource Selection

During both winter periods, black scoter core-use areas were closer to shore and had shallower water depths, coarser sediment grain size, and higher probability of hard-bottom occurrence relative to available areas (Table 3). The highest-ranked habitat selection models differed slightly between the 2 winter periods (Table 4). The top model for the 2010–2011 winter period accounted for 0.69 of Akaike weight and included the parameters distance to shore, grain size, and hard-bottom probability. The second-ranked model for the 2010–2011 winter period had a ΔAIC_c value <2, but was not considered competitive because it differed from the top model by a single uninformative parameter (Arnold 2010). For the 2011–2012 period, the top model accounted for 0.83 of Akaike weight and included water depth and all parameters present in the 2010–2011 model. Parameter estimates from the 2011–2012 winter model showed a slightly weaker negative effect of grain size and slightly stronger positive effect of hard-bottom probability relative to the winter of 2011–2012 (Table 5). For each winter, results of the k-fold cross-validation indicated strong positive correlation (0.78–0.99) among area adjusted frequencies and increasing RSF bins, indicating that the RSF models were capable of reliably predicting cross-validated use locations.

Maps of relative probability of selection using the top-ranked models extrapolated across the RI Ocean SAMP

Table 3. Mean ($\bar{x}$) and standard error (SE) of habitat variables in utilization distributions (available) and core-use areas (used) of black scoters along the southern New England continental shelf during the 2010–2011 and 2011–2012 winter periods.

Period	Habitat variable	Available[a] $\bar{x} \pm$ SE	Used[a] $\bar{x} \pm$ SE
2010–2011	Distance to shore (km)	6.2 ± 0.1	4.0 ± 0.3
	Water depth (m)	17.7 ± 0.3	15.2 ± 0.7
	Grain size (phi scale)	1.34 ± 0.02	0.97 ± 0.07
	Hard bottom probability (0–1)	0.06 ± 0.0	0.23 ± 0.02
2011–2012	Distance to shore (km)	6.5 ± 0.2	3.9 ± 0.2
	Water depth (m)	21.0 ± 0.5	13.2 ± 0.6
	Grain size (phi scale)	1.34 ± 0.02	0.71 ± 0.05
	Hard bottom probability (0–1)	0.07 ± 0.0	0.16 ± 0.01

[a] Sample size for each habitat variable ranged from 1,308 to 1,385 for the utilization distributions (available) and 144 to 193 for the core-use areas (used).

study area predicted similar patterns of selection by black scoters among the 2010–2011 and 2011–2012 winter periods (Fig. 5A and B, respectively). Between years, percent of spatial overlap among quantile classes was highest (68%) for the high-selection classification and ranged from 30–62% for medium-high to low-selection classifications.

DISCUSSION

Phenology and Length of Stay During Winter
Our results from satellite-tagged birds confirmed the importance of this region for black scoters during winter. Migration chronology of black scoters during this study generally concurred with previous research in southern New England (Veit and Petersen 1993) with peak numbers

occurring from late October through mid-November, and from late March to mid-April, although we documented a protracted departure from southern New England through late-May of some tagged scoters. Tagged males arrived over 1 week earlier than females, which agreed with movements documented by Bordage and Savard (1995). During spring, male black scoters are thought to follow females to breeding sites (Bordage and Savard 1995); however, we found that migratory departure dates spanned a nearly 3-month period with no obvious departure difference between males and females. Satellite-tagged black scoters spent nearly 50% of their annual cycle (median = 150 days, range = 83–183 days) on southern New England wintering grounds, although half of the satellite-tagged black scoters made forays of varying lengths to other major wintering locations including Delaware Bay, Chesapeake Bay, and coastal North Carolina. A similar length of stay (44%) and tendency for forays was reported for king eiders (*Somateria spectabilis*) tracked throughout their wintering grounds in the Bering Sea, and over half of these individuals used multiple wintering sites located at least 50 km apart (Oppel et al. 2008). The implications for siting of offshore wind energy developments are that individual black scoters are likely to encounter offshore facilities in southern New England during 3–5 months from late-October to mid-April, and their foraying behavior would increase encounters with the multiple proposed offshore wind energy developments throughout the Atlantic Coast and thus potentially increase their risk of cumulative impacts.

Satellite-tagged black scoters also exhibited weak site fidelity to wintering areas between years, which may allow them to find alternative foraging or roosting sites if displaced

Table 4. Number of model parameters (K), maximized log-likelihood [log(L)], second-order Akaike Information Criterion for small sample sizes (AIC$_c$), AIC$_c$ differences (ΔAIC$_c$), and AIC$_c$ weights (w_i) for each of the 12 candidate a priori logistic regression models of winter habitat use versus availability developed for black scoters within the southern New England continental shelf study area during the 2010–2011 and 2011–2012 winter periods. Model parameters include distance to shore (DS), mean sediment grain size (GS), hard-bottom probability (HBP), and water depth (WD).

Period	Model parameters	K	log(L)	AIC$_c$	ΔAIC$_c$	w_i
2010–2011	DS, GS, HBP	4	−410.28	828.6	0.0	0.69
	DS, WD, GS, HBP	5	−410.24	830.5	1.9	0.26
	WD, GS, HBP	4	−413.12	834.4	5.8	0.04
	DS, HBP	3	−415.81	837.6	9.0	0.01
	WD, HBP	3	−417.52	841.1	12.5	0.00
	HBP	2	−419.53	843.1	14.5	0.00
	DS, GS	3	−444.97	896.0	67.4	0.00
	DS	2	−458.78	921.6	93.0	0.00
	WD, GS	3	−460.31	926.6	98.0	0.00
	GS	2	−463.99	932.0	103.4	0.00
	WD	2	−473.99	952.0	123.4	0.00
	Intercept only	1	−477.40	956.8	128.2	0.00
2011–2012	DS, WD, GS, HBP	5	−488.83	987.7	0.0	0.83
	WD, GS, HBP	4	−491.53	991.1	3.4	0.15
	DS, GS, HBP	4	−494.30	996.6	8.9	0.01
	DS, GS	3	−497.78	1001.6	13.9	0.00
	WD, GS	3	−499.10	1004.2	16.5	0.00
	GS	2	−519.12	1042.2	54.5	0.00
	WD, HBP	3	−536.59	1079.2	91.5	0.00
	DS, HBP	3	−546.21	1098.4	110.7	0.00
	WD	2	−555.26	1114.5	126.8	0.00
	DS	2	−557.98	1120.0	132.3	0.00
	HBP	2	−560.71	1125.4	137.7	0.00
	Intercept only	1	−582.35	1166.7	179.0	0.00

Table 5. Coefficents (β) and 95% confidence intervals (lower and upper) of best-fit resource selection models for black scoters wintering along the southern New England continental shelf in 2010–2011 and 2011–2012.

	2010–2011			2011–2012		
Variable	β	Lower	Upper	β	Lower	Upper
Water depth (m)				−0.0322	−0.0527	−0.0128
Distance to shore (km)	−0.0832	−0.139	−0.0301	−0.0697	−0.133	−0.0104
Grain size (phi scale)	−0.381	−0.617	−0.152	−1.0614	−1.307	−0.823
Hard bottom probability	4.0204	3.0767	4.982	1.445	0.536	2.339

by offshore development. Less than half of the black scoters that wintered along the southern New England shelf during 2010–2011 returned to winter in the region during 2011–2012. Of these, only 33% used predominately the same core-use areas during the subsequent winter period. These dynamic movements between and within winters may enable black scoters to exploit ephemeral prey as has been documented in surf (*Melanitta perspicillata*) and white-winged scoter (*M. fusca*; Lok et al. 2008), respond to prey depletion as seen in surf scoters (Kirk et al. 2008), or find alternate sites as documented among king eider (Oppel et al. 2009). Pair formation for black scoters is thought to occur on the wintering grounds (Bordage and Savard 1995) and thus winter dispersal may also facilitate gene flow (Anderson et al. 1992).

Figure 5. Relative probabilities (quartiles), shaded from light gray (lowest probability, <25%) to dark gray (highest probability, >75%) of habitat use by satellite-tagged black scoters predicted across the Rhode Island Ocean Special Area Management Plan (RI Ocean SAMP) marine spatial planning area (dashed line) by the top-ranked resource selection function models for the 2010–2011 winter period (A, top), and the 2011–2012 winter period (B, bottom) in relation to Block Island (white cross-hatching) and Rhode Island/Massachusetts Area of Mutual Interest (RI/MA AMI; black diagonal-hatching) Renewable Area Zones.

Utilization Distributions

The winter kernel-based home range sizes reported by various other sea duck studies are considerably smaller than the winter ranges of black scoters that we observed along the southern New England shelf. Winter utilization distributions of individual black scoters in our study ranged from <20 to >10,000 km² with no differences detected between sexes. Large variation in the total area of minimum convex polygon winter ranges (13–66,722 km²) was also reported for 92 satellite-tagged king eiders in the Bering Sea, with no differences observed between sexes or among years (Oppel et al. 2008). In comparison, winter utilization distributions were on average 11.5 km² for harlequin ducks (*Histrionicus histrionicus*) in Prince William Sound (Iverson and Esler 2006) and 67.8 ± 8.3 km² for common eiders (*Somateria mollissima*) in southwestern Greenland (Merkel et al. 2006). In dynamic winter environments, a variety of factors may be associated with sea duck movements including prey depletion (Kirk et al. 2008), exploitation of ephemeral prey (Lok et al. 2008), prospecting alternate sites (Oppel et al. 2009), and mate seeking (Robertson et al. 2000). The large winter ranges of black scoters that we documented increases the likelihood that they would encounter offshore wind energy facilities compared to other seaducks that range less widely.

Resource Selection

Because sea ducks are capable of ranging widely in response to dynamic conditions, marine spatial planning efforts should consider habitats predicted by resource selection models and assume that they may be used sporadically by sea ducks over time and space (Lovvorn et al. 2009, Dickson and Smith 2013). Satellite-tagged black scoters in our study area used nearshore (<5 km), subtidal habitats (<20 m) adjacent to the mainland coast or offshore islands. Following Johnson's (1980) third-order resource selection criteria, black scoters during this study tended to select in shallow areas (50% isopleth; averaging 13–15 m). In Europe, common scoters (*Melanitta nigra*) typically forage to depths less than 20 m during winter (Fox 2003), although they can dive offshore at depths exceeding 20 m (Nilsson 1972). Foraging sea ducks tend to concentrate in areas with abundant macroinvertebrate prey (Guillemette et al. 1993), and along the southern New England shelf, peak bivalve density occurs in nearshore areas at depths <26 m (Theroux and Wigley 1998). Molluscivorous sea ducks such as black scoters were displaced for at least 3 years post-construction (Peterson et al. 2007) by offshore wind energy developments in Europe (Garthe and Hüppop 2004, Kaiser et al. 2006,
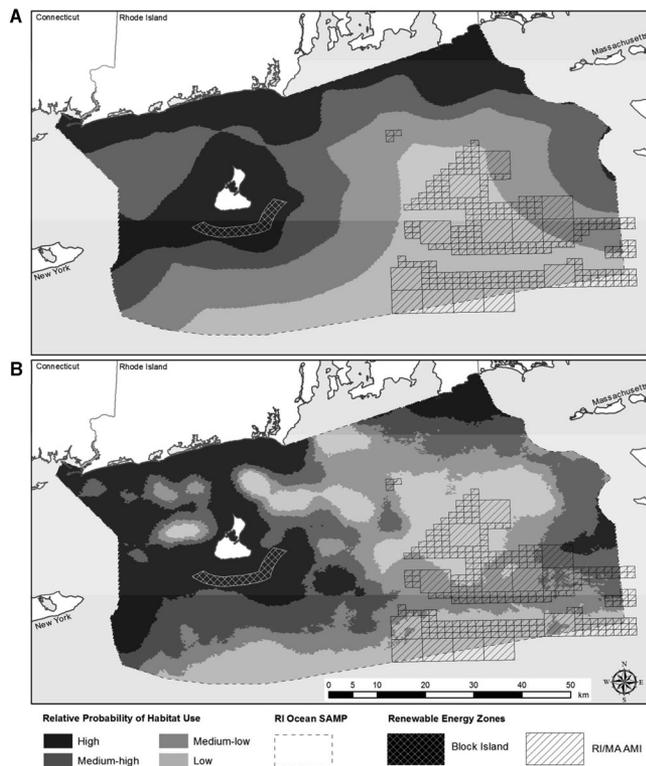
Petersen et al. 2006). Thus, offshore wind developments in our region that are placed in shallow habitats (<20 m) are more likely to displace scoters from potential foraging habitat.

Black scoters wintering in southern New England selectively used coarse, sandy substrates, apparently to take advantage of relatively abundant and accessible benthic prey much like Stott and Olson (1973) documented for black scoters in coastal New Hampshire, and Fox (2003) found for common scoters in western Europe. In Rhode Island, benthic communities associated with coarse-sand habitats had high densities of homogeneously distributed infaunal bivalves (*Ensis directus*, *Tellina* spp.) and dense assemblages of tube-dwelling, *Ampeliscid* amphipods (Loring et al. 2013). We also found that black scoters often occupied hard-bottom substrates. Farther north in Newfoundland, black scoters primarily consumed blue mussels (*Mytilus edulis*) where hard-bottomed substrate was widespread (Goudie and Ankney 1986). Although the distribution of sea ducks during winter is largely driven by benthic prey (Stott and Olson 1973, Larsen and Guillemette 2000), other important factors in our region and elsewhere may include currents (Holm and Burger 2002), salinity (Phillips et al. 2006), exposure (McKinney and McWilliams 2005), social cues (Clark and Mangel 1984), predation risk (Reed and Flint 2007), shoreline development (McKinney et al. 2006), and disturbance (Larsen and Laubek 2005).

MANAGEMENT IMPLICATIONS

Managers interested in protecting wintering habitat for black scoters should prioritize shallow (<20 m deep), nearshore (<5 km from land) areas that consist of hard-bottomed or coarse-sand substrates. Based on the importance of shallow foraging habitat for seaducks, the RI Ocean SAMP prohibits the construction of any offshore wind energy developments in waters less than 20 m deep (RI Ocean SAMP 2012). Our models classified the 5-turbine Block Island Renewable Energy Zone as having a high probability of use by black scoters; therefore, some foraging black scoters are likely to be displaced if this offshore wind energy development is constructed. The 200-turbine federal lease block zone in the center of Rhode Island Sound was classified as medium-low to low probability of use by black scoters because the site is in deeper waters and is farther from shore. However, large composite core-use areas were consistently present in nearshore areas surrounding the federal lease blocks. Therefore scoter movements between core-use areas throughout their 3–5 month winter stay in southern New England could increase vulnerability to collision risk and cause barrier effects (Fox et al. 2006, Langston 2013), although available studies suggest that collision risk is low for sea ducks (Desholm and Kahlert 2005) and the energetic costs of displacement are minimal (Masden et al. 2009). If offshore wind energy developments become prevalent throughout the wintering range of black scoters along the Atlantic Coast of North America, the cumulative impacts on marine birds, in general, and black scoters, specifically, could become a management concern (Masden et al. 2010).

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