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## BODY COMPOSITION, MOVEMENT PHENOLOGY AND HABITAT USE OF COMMON EIDER ALONG THE SOUTHERN NEW ENGLAND COAST

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**BODY COMPOSITION, MOVEMENT PHENOLOGY AND  
HABITAT USE OF COMMON EIDER ALONG THE  
SOUTHERN NEW ENGLAND COAST**

**BY**

**JOSHUA M. BEUTH**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE**

**REQUIREMENTS FOR THE DEGREE OF**

**MASTER OF SCIENCE**

**IN**

**BIOLOGICAL AND ENVIRONMENTAL SCIENCES**

**UNIVERSITY OF RHODE ISLAND**

**2013**

MASTER OF SCIENCE THESIS

OF

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DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND  
2013

## ABSTRACT

The nearshore and offshore waters of southern New England provide important winter habitat for many sea duck species including common eiders (*Somateria mollissima*). Sea ducks that inhabit these waters must contend with global climate change, disease, and anthropogenic disturbance including proposed offshore wind energy development; however, evaluating these potential impacts on sea ducks, in general, and eiders in particular is difficult because knowledge of their ecology during winter is limited. I conducted the first validation of a non-lethal method for estimating body composition (deuterium dilution) of eiders and then applied this method to assess changes in body composition throughout the winter of 2011-12. I constructed models using deuterium-estimated body water, structural measurements, body mass and sex that estimated wet lean mass with 2.0 % relative error, and fat mass with 20.2 % relative error. Both male and female eiders were heavier and had more fat in late winter compared to early winter, whereas wet lean mass remained constant for males and declined over time for females from early to late winter. Based on model accuracy, the deuterium dilution method provided a viable, non-lethal approach for estimating body composition of eider. Biologists interested in assessing the potential impacts of offshore wind energy development and exposure to diseases such as Wellfleet Bay Virus on body composition of eider could use the method to assess changes in body condition. In a complimentary second study, I used satellite telemetry to track the movements of 26 adult female common eiders from November 2011 to July 2013 to delineate the migratory phenology, home ranges, habitat use and site fidelity of eiders that were initially captured during early-winter in southern New England. Eiders exhibited high fidelity to the southern New

England wintering area (19 of 23 birds returned to the same area between years), where birds spent approximately 38% of their annual cycle. Birds were relatively sedentary during winter with home ranges that tended to be smaller than other species of seaducks ( $\bar{x}$  -50% kernel core use areas = 38.5 km<sup>2</sup> and  $\bar{x}$  -95% kernel utilization distributions = 199.3 km<sup>2</sup>). Satellite-tagged eiders wintering in southern New England migrated to 4 summer areas in Maine, USA, Nova Scotia, the St. Lawrence Estuary and the Gulf of St. Lawrence, Canada. During winter, eiders preferred shallow waters that were closer to shore, and that had relatively fine-sediment substrate and a higher probability of hard bottom. I used this information to develop a spatially-explicit model that predicted that approximately 13.1% of this 6,212 km<sup>2</sup> study area had a medium-high to high relative probability of use by eiders, and identified relatively high-use areas. Managers and policy makers could use this information to evaluate certain siting scenarios for offshore wind energy development so that areas with a high probability of use by eiders are avoided, thus minimizing the chance of negative impacts on the species.

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## **PREFACE**

This thesis follows the University of Rhode Island Graduate School guidelines for manuscript formatting. Manuscript 1 is titled “Validating the Deuterium Dilution Method to Assess Changes in Body Composition of Common Eiders During Winter” and is formatted for submission to the journal *Wildlife Society Bulletin*. Manuscript 2 is titled “Habitat Use and Movement Dynamics of Common Eiders in Southern New England Relative to Offshore Wind Energy Development” and is formatted for submission to the *Journal of Wildlife Management*.



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**MANUSCRIPT – 1**

*Formatted for the journal Wildlife Society Bulletin*

**Validating the Deuterium Dilution Method to Assess Changes in Body Composition of Common Eider During Winter**

RH: Beuth et al. • Common eider body composition

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**KEY WORDS** body composition, body condition, common eider, deuterium dilution, offshore wind, *Somateria mollissima*, southern New England, winter.

**ABSTRACT** Thousands of sea ducks winter along the nearshore and offshore waters of southern New England and these waters have been recently considered for offshore wind energy development. Anthropogenic disturbances introduced into habitat used by wintering eider have the potential to negatively impact their body condition. Biologists presently lack an accurate, non-lethal method for measuring body composition of sea ducks that allows them to assess body condition. Our goal was to validate the deuterium dilution method for measuring body composition American common eiders (*Somateria mollissima dresseri*). We captured 19 eiders during winter in southern New England, injected each eider with  $1,066 \pm 4.5$  mg of 99.9% deuterium oxide, allowed them to rest for 90 minutes and then collected approximately 200 ul of blood from each eider. We euthanized eiders after collecting blood, recorded structural measures, and performed a carcass analysis. We measured deuterium concentration in blood water using an isotope ratio mass spectrometer, from which we estimated total body water. Deuterium over-estimated body water by  $13.30 \pm 0.73\%$  ( $R^2 = 0.931$ ). We derived linear regression models using combinations of 5 variables to estimate wet lean and fat mass. Using a jack knife validation, we determined that the top two models predicted with 2.04 and 2.02 % relative error, respectively, and the top ranked fat mass model predicts with 20.24% relative error. Using these models we determined that both male and female eiders significantly increased fat mass in late winter compared to early winter, whereas wet lean mass of males remained constant throughout the winter, while wet lean mass of females was significantly less than males during late winter and decreased compared to early winter. Deuterium dilution is a method that enables field biologists to obtain relatively

accurate measurements of common eider body composition without needing to kill the bird to perform extensive and expensive total carcass analyses.

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Biologists interested in an animal's health often measure body condition, which wildlife biologists define as an individual's fat content relative to morphometrically-estimated size (Green 2001; Labocha and Hayes 2012) or more broadly as "the energy capital accumulated in the body as a result of feeding" (Peig and Green 2009). Investigations of body condition have broad relevance for the ecology and management of free-living wildlife (Servello et al. 2005) because they relate to habitat requirements, can indicate habitat quality (Moon et al. 2007, Schummer et al. 2012), so can be a useful integrative indicator of environmental disturbance at a variety of scales including that associated with global climate change, disease, and anthropogenic development (Klaassen et al. 2012).

Estimates of body condition of waterfowl are especially common (Campbell and Leatherland 1980, Alisauskas et al. 1990, Jamieson et al. 2006a) in part because body composition of ducks and geese changes quite dramatically across seasons (Reinecke and Stone 1982, Badzinski et al. 2011) and because nutrient stores of females during winter and spring migration affects reproductive investment (Korschgen 1977, Ankney et al. 1991). Studies of waterfowl body condition during winter have primarily focused on dabbling and diving ducks (Baldassarre et al. 1986, Whyte et al. 1986, Morton et al. 1990, Schummer et al. 2012), whereas few investigators have focused on sea ducks (Jamieson et al. 2006b) despite recent declines in many sea duck populations that may be related to their ecology and condition (Caithamer et al. 2000, Goudie et al. 2000).

Understanding body condition of wintering waterfowl including sea ducks is critical because individuals with lower body mass relative to body size have reduced annual survival rates (Haramis et al. 1986, Hepp et al. 1986, Hohman et al. 1995, but see Krementz et al. 1989) in part because birds in poor body condition may be more vulnerable to predation (Guillemette et al. 1992) and diseases (Navarro et al. 2003, Hanssen et al. 2005, Bourgeon et al. 2006, Owen and Moore 2008, but see Arsnoe et al. 2011). In addition, there is a pressing need to understand how body condition of wintering sea ducks is affected by displacement from offshore wind energy developments (OWED; RI Ocean SAMP 2010, BOEM 2012), regional diseases (Ellis et al. 2010), and other potential anthropogenic disturbances (Merkel et al. 2009, Schwemmer et al. 2011, Klimstra and Padding 2012). Offshore wind energy development in Europe may alter body composition of sea ducks because these facilities displace birds from preferred habitats (Petersen et al. 2006), cause at least short-term avoidance of the area between turbines (Petersen and Fox 2007), and create barriers to diel movements and thus increase flight times (Desholm and Kahlert 2005).

Body condition of animals can be assessed using direct or indirect methods (Campbell and Leatherland 1980, Speakman 2001, Jamieson et al. 2006a). Direct methods are lethal because they involve directly measuring the total amount of fat and/or lean mass (protein) in individuals (Hicks 1967, McLandress and Raveling 1981, Ellis and Jehl 1991, Alisauskas et al. 1990, Jamieson et al. 2006a). Jamieson et al. (2006a) recommended directly measuring body composition of common eider (*Somateria mollissima*) and this method has been commonly used for other waterfowl (Ankney and MacInnes 1978, Reinecke et al. 1982, Baldassarre et al. 1986, Schummer et al. 2012).

Indirect methods allow body composition to be estimated without the need to sacrifice the birds (Speakman 2001, McWilliams and Whitman 2013) and avoid the laborious dissections and complex analyses required for directly measuring body composition (Johnson et al. 1985). Deuterium dilution is an indirect method that has been successfully applied to estimate body composition of a variety of wild vertebrates (Speakman 2001) including song-birds (McWilliams and Whitman 2013) and Barnacle Geese (*Branta leucopsis*) (Eichhorn and Visser 2008), although no previous studies have used this indirect method to assess body composition dynamics of sea ducks.

Common eider (hereafter eider) are the largest species of North American sea duck, are widespread and abundant during winter in northeastern North America (Goudie et al. 2000, Silverman 2013), and thus are an ideal species for investigating how body composition changes throughout the winter in relation to environmental, disease and anthropogenic factors. Thousands of American common eider (*S. m. dresseri*) winter nearshore in southern New England (Klimstra and Padding 2012, Silverman et al. 2013) where eider are exposed to harvest by hunters (Raftovich et al. 2011), habitat loss and degradation (Goudie et al. 2000, Thrush and Dayton 2002), novel diseases (Ellis et al. 2010) and inclement weather. In addition, efforts to develop separate large and small scale OWED projects are advancing in Rhode Island (RI OCEAN SAMP 2010, BOEM 2012), intensifying the need to understand the potential impacts of OWED on sea duck body composition in southern New England. Simultaneously, Wellfleet Bay Virus (WBV), a newly emerging regional disease (A. Allison, Cornell University, personal communication) that threatens eiders in southern New England has been responsible for die-offs ranging from several hundred to several thousand eiders annually (Ellis et al.



2010). Although body composition of eider likely influences their response to anthropogenic disturbance and disease risk, the only baseline study of the body composition dynamics of eider during winter was conducted on the smaller northern common eider (*Somateria mollissima borealis*) (Jamieson et al. 2006a) that winters in more northern latitudes. The specific goals of this study of American common eider were to: 1) validate for the first time the deuterium dilution method for estimating body composition of eider, 2) use deuterium dilution to estimate and compare body composition of adult eider throughout the wintering period while they inhabit the southern New England wintering area, and 3) compare the body composition dynamics during winter of the two subspecies of eider that reside at different latitudes.

## **STUDY AREA**

Our study area included nearshore and offshore waters of southern New England, which we define as all waters extending east from Montauk Point, Long Island, New York to Cape Cod and Cape Cod Bay, Massachusetts (Figure 1). The southern New England continental shelf has many offshore islands of varying sizes; most notably Block Island, Rhode Island, and Martha's Vineyard and Nantucket, Massachusetts. Rocky reefs and sporadic mussel beds in southern New England provide eider excellent foraging opportunities for benthic invertebrates (Theroux and Wigley 1998), such as blue mussels (*Mytilus edulis*) and green crabs (*Carcinus maenas*) (Loring et al. 2013), which are preferred food sources of eider (Ydenberg and Guillemette 1991). The nearshore waters of southern New England are generally shallow with increased depth gently sloping seaward (Theroux and Wigley 1998, Eakins et al. 2009), which provides extensive habitat for eider and other sea ducks because they prefer to forage in water depths up to

20 m (Goudie et al. 2000). As such, southern New England supports the highest densities of wintering sea ducks on the Atlantic Coast (Silverman et al. 2013).

## **METHODS**

### **Capture of Eider**

We used floating mist nets surrounded by decoys (Brodeur et al. 2008) to capture eiders at several locations in southern New England (Fig. 1) during 3 time intervals: early winter (November 2011, 2012, December 2011,  $n = 139$ ), mid-winter (February 2012,  $n=47$ ), and late winter (March 2012,  $n=37$ ). We deployed 3 pairs of mist nets (net size: 1.3 m x 18 m, 127-mm mesh) over near shore (<1 km) feeding locations from pre-dawn until 2-4 hrs after sunrise. Teams of 2-4 biologists in 6-7 m outboard skiffs remained approximately 100 m from each active mist net to closely monitor and determine where eider were captured. We immediately removed captured birds from mist nets, recorded their age as after hatch year (adult) or hatch year and gender (based on wing plumage characteristics described by Carney (1992)) and measured body mass with a Pesola spring scale ( $\pm 5$ g).

### **Measuring Body Composition**

*Field methods.*—Our goal was to capture and estimate body composition of 30 adult eiders during each of the 3 winter periods (early, mid and late). In addition, we captured 21 adult eiders for the validation of the deuterium dilution method. These 21 adult eider were caught throughout the winter (early winter  $n = 16$ , mid-winter  $n = 4$ , later winter  $n = 1$ ) and were selected to span the full range of body weights of captured eider (1533 to 2298 g) (Table 1). We used 111 of the 148 adult eiders captured during fieldwork (early winter  $n=51$ , mid-winter  $n=33$ , late winter  $n=27$ ) for inclusion in this body composition

study and immediately released after banding the other 37 adults, as well as all 75 juvenile eiders. We included more adult eider during early winter because this project was part of a larger satellite telemetry study (Chapter 2) for which we estimated body composition of eiders when transmitters were deployed.

Within 30 min of capture in the field, we used a pre-filled, disposable 1-ml insulin syringe (Fischer Scientific, 22004270) to inject into the pectoral muscle of each of 107 eider on average  $1,066 \pm 4.5$  mg of 99.9% deuterium oxide (Sigma Aldrich Co. 151882-100G). Four eiders captured and injected in Wellfleet, Massachusetts (Fig. 1), were injected with on average  $3,148 \pm 34.3$  mg of the same 99.9% deuterium oxide solution in order for concentrations to be determined using an infrared spectrophotometer available in our laboratory. We measured actual mass of deuterium oxide injected into each bird by reweighing syringes after injection and subtracting this from the pre-injection mass of the same syringe plus deuterium oxide solution. After injection we housed birds in individual pet crates (48cm x 32cm x 26 cm height) for 1.5 hrs to allow deuterium oxide to reach equilibrium in their pool of body water (Eichhorn and Visser 2008). On average 97 min ( $\pm 9$  min) after injection, we collected approximately 200 ul of blood into heparinized capillary tubes (Fischer Scientific, 22362566) after pricking the medial metatarsal vein of each bird with a sterile 27G needle (Fischer Scientific, 1482648). In the field, we sealed capillary tubes with blood using clay, and later the same day we flame-sealed the glass capillary tubes and stored blood samples at 4.4° C.

We immediately released 90 eiders (approximately 30 each in early, mid, and late-winter) after collecting these post-injection blood samples, whereas we used cervical dislocation to kill the 21 eider that were used for the validation study. In the field, we did

not measure structural size (i.e., head and bill characters, tarsus length, wing chord) because of the limited time we held the eider to minimize handling stress, and because accurately measuring these structural size characters is difficult in small skiffs on the ocean during winter. Consequently, these structural measures were measured only in the 21 validation birds transported to the laboratory (see below). We stored euthanized eiders in the field for a maximum of 6 hrs in zip-lock bags at ambient temperature until we returned to the laboratory. In the laboratory, we reweighed each specimen using an electronic balance ( $\pm 0.1$  g), double-bagged each bird in a freezer zip-lock bag, and stored frozen specimens ( $-17^{\circ}$  C) until we completed total carcass analysis.

We conducted all methods with approval of the University of Rhode Island Institutional Animal Care and Use Committee (Protocol # AN 11-09-004).

*Laboratory methods: total carcass analysis.*—We used the 21 eider selected as validation birds to develop the predictive relationship between total body water (estimated using deuterium dilution) and body composition as directly measured from carcass analysis (Eichhorn and Visser 2008, McWilliams and Whitman 2013). We used standard techniques outlined by Dobush et al. (1985) and Speakman (2001) to directly measure body composition (total body fat mass, lean mass, water, protein, and feathers) of the 21 eider. Briefly, we thawed frozen eider carcasses for approximately 2 hrs and weighed each on an electronic scale ( $\pm 0.1$  g). We measured the following structural characters with calipers to the nearest 0.01 mm: culmen length, culmen width at nares, head length, and tarsus length (Dzubin and Cooch 1992). We also measured flattened wing chord to the nearest mm. We repeated structural measures 5 times and used the mean of the replicates for statistical analysis. We then shaved and reweighed each eider

and used the difference between unshaved and shaved body mass to estimate feather mass. We used a butcher's saw to section the carcass into smaller pieces and then ground the carcass using a commercial meat grinder (Hobart Corporation, Troy, Ohio). To ensure complete homogenization, we ground and homogenized each carcass 4 times. We sub-sampled the homogenized carcass for measurement of water, protein and fat as described below.

*Measuring total body water.*—We dried 6, 50-g samples of each homogenized carcass in aluminum trays at 90° C until constant mass. We calculated water content (%) of the sample as the difference between the fresh wet mass and dry mass of the sample divided by the fresh wet mass of the sample. We estimated total body water by multiplying the mean water content (%) of the 6 subsamples by the shaved carcass mass.

*Measuring fat mass.*—We dried 4, 50-g samples of each homogenized carcass in aluminum trays at 60° C until mass was constant (Dobush et al. 1985). Once dry, we combined the samples and homogenized them using a blender. From this dry, homogenous mixture, we weighed 5, 1.0-g subsamples into cellulose thimbles that we had previously dried at 60° C and weighed. We placed thimbles into a Soxhlet extractor and refluxed the samples with petroleum ether (Dobush et al. 1985) for a minimum of 8 hrs. After a visual inspection verified that the ether flushing through the thimbles was clear and free of fat, we removed the thimbles and dried them overnight at 60° C. We re-weighed the dried thimbles and calculated fat (%) as the difference between dry sample mass and lean-dry sample mass, divided by the dry sample mass. We estimated total fat as the mean percent fat of the 5 samples multiplied by the dry shaved carcass mass.

*Measuring protein.*—We combined and re-homogenized the lean, dry samples resulting from fat extraction from each carcass. Using a Wiley Mill (screen size 40), we further homogenized the lean, dry samples. We measured 5, 1-mg replicates of lean, dry homogenate, into 4 × 6 mm aluminum capsules (Costech Inc., Valencia, CA). We directly measured nitrogen content using a continuous flow isotope ratio mass spectrometer (Elementar Americas, Mt. Laurel, NJ). For 11 of 21 eider, our measurement of nitrogen content had CV > 5%, so we re-measured nitrogen content for 5 additional replicates to reduce the CV < 5%. We estimated nitrogen content of the carcass as the mean percent nitrogen of the replicates multiplied by the lean, dry shaved carcass mass. We determined the amount of protein in each bird by multiplying the nitrogen content by 6.25 (Parker and Holm 1990). As expected, total protein estimated from nitrogen content was closely related to total lean dry mass across individuals ( $R^2 = 0.865$ ,  $P < .0001$ ), so we report below only the results for total lean mass.

*Measuring deuterium concentration.*—We measured the deuterium concentration (atom %) in each blood sample from the 111 eider to estimate the total body water and body composition of eider throughout winter. We first microdistilled each blood sample following procedures described by Nagy (1983) to recover a blood water sample. Deuterium concentration in blood water was measured by the University of Arkansas Stable Isotope Laboratory (UASIL, Fayetteville, AR, USA) using a high temperature conversion elemental analyzer (TC/EA) (Thermo Finnigan, Waltham, MA) interfaced with a Conflo III (Thermo Finnigan) to a Delta plus XP with electrostatic filter mass spectrometer (Thermo Finnigan). We analyzed 4 1- $\mu$ l sub-samples of each blood water sample, with the last 2 retained and averaged while the first 2 replicates were discarded to

minimize carry over from the previous sample. We converted deuterium enrichment in parts per million (ppm) to atom percent concentration using the following equation:

$$\text{Atom \%} = (100 \times 0.0001557 \times (X / 1000 + 1) / (1 + 0.0001557 \times (X / 1000 + 1))$$

Where 0.0001557 was the mole fraction of deuterium in VSMOW (Coplen et al. 2002), and  $X$  was the measured deuterium enrichment (ppm) of the sample.

*Measuring background deuterium.*—We measured background deuterium concentration (atom %) in 4 eiders that were not used in the validation of the deuterium dilution method or for estimation of body composition. Mean background deuterium concentration was  $0.01536 \pm 2.091 \text{ e}^{-5}$  atom %. We corrected measured deuterium concentrations of all blood samples by subtracting the mean background deuterium concentration.

*Estimating total body water.*—We used the following equation from Karasov and Pinshow (1998) and McWilliams and Whitman (2013) to estimate deuterium space (total body water):

$$E = 100 \times \{0.999 \times (B/20) / [0.999 \times (B/20) + 0.001 \times (B/18) + (S/18)]\}$$

Where  $E$  was the measured enrichment (atom %) of deuterium in the sample after background correction, 0.999 was the proportion of injected solution that was deuterated water, 0.001 was the proportion of injected solution that was unlabeled water,  $B$  was the injection mass in grams, 20 was the molar mass of deuterated water, 18 was the molar mass of unlabeled water and  $S$  was deuterium space (or body water) in grams. Knowing actual amount of deuterium injected ( $B$ ) and measured enrichment ( $E$ ), we rearranged the equation to estimate the deuterium space (total body water):

$$S \text{ (g)} = 18 \times (((100 \times (0.999 \times (B/20)))/E) - (0.999 \times (B/20)) - (0.001 \times (B/18)))$$

## **Estimating Body Composition**

*Model development.*—We used multiple regression analysis to compare predictive models to estimate wet lean and fat mass of eider given deuterium-estimated total body water, structural size, body mass, and sex of each bird. We used principal component analysis to condense the 5 structural measurements and body mass into 2 orthogonal principal components that were then included in the multiple linear regression analyses. We used Levene’s test and examination of Q-Q plots to ensure the dependent variables met the assumptions of normality and homoscedasticity. We used SAS 9.2 (SAS Institute, Inc., Cary, NC) to perform all statistical analyses unless otherwise noted. We also used non-linear regression (SYSTAT, Version 5; Wilkinson 1992) to estimate fat mass given deuterium-estimated body water and body mass as described in previous studies (Campbell and Leatherland 1980, Karasov and Pinshow 1998, McWilliams and Whitman 2013).

*Model selection and evaluation.*—We used Akaike’s information criterion (AIC) corrected for small sample sizes (AIC<sub>c</sub>) and estimates of the accuracy of model predictions to select the best model(s), and a jack-knife approach for model validation. Briefly, we ran 19 iterations of each model, excluding the measured water, lean and fat mass for 1 individual bird during each of the iterations and used the measured values from the remaining 18 birds to estimate the total water, wet lean mass, and fat mass of the excluded bird. The accuracy of these estimated values was assessed by comparing the root mean square error (RMSE), absolute error, and relative errors for each model. Root mean square error was calculated using the following equation:

$$\sqrt{(\sum(y_p - y_m)^2/n)}$$



where  $y_p$  is the predicted value,  $y_m$  is the measured value and  $n$  is the number of birds over which the squared difference between predicted and measured was summed. We also calculated for each individual bird the Absolute error (g) as |predicted - measured| and the relative error (%) as (absolute error/measured)  $\times$  100.

*Estimating body composition of unknowns.*—We used the predictive models to estimate the body composition of 90 eiders (approximately 30 each seasonal period) that we injected with deuterium, bled ca. 100 min after injection, and then released during early, mid and late winter. We used analysis of variance (ANOVA) with Tukey's multiple comparisons (SAS Institute, Inc., Cary, NC) to compare body mass, estimated wet lean mass and estimated fat mass between males and females across the 3 winter time periods.

In order to compare our model-estimated body composition to other studies (e.g., lesser snow geese (*Chen caerulescens*) (Campbell and Leatherland 1980) and songbirds (Karasov and Pinshow 1998, McWilliams and Whitman 2013)), we also used non-linear regression to estimate fat mass given deuterium-estimated total body water and body mass using the following equation:

$$\text{fat} = mb - \text{deutmw} - (\text{deutmw}/B_o)$$

where *fat* is wet fat (g), *mb* is body mass (g), *deutmw* is deuterium-estimated total body water, and  $B_o$  is the ratio of deuterated water mass to dry fat mass (Karasov and Pinshow 1998). We used nonlinear regression to estimate  $B_o$  (3.092), which was within the range of other validation studies (Karasov and Pinshow 1998, McWilliams and Whitman 2013), and then fat mass of each bird given their *mb* and *deutmw*.

## **RESULTS**

### **Capture of Eider**

From 2011-2012, we captured 148 adult and 75 hatching year eider. Body mass of all adult eider was on average 1934.8 g (range = 1420-2320 g,  $n = 148$ ) whereas that of adult eider used to assess body composition throughout winter was on average 1960.1 g (range = 1420-2320 g,  $n = 19$ ). Adult eiders selected for the deuterium dilution validation included light and heavy birds as well as individuals from throughout the normal distribution of body mass of all adult eider (Table 1).

### **Body Composition and Size of Validation Eider**

Male eiders averaged 280 g heavier than females ( $t_{17} = -3.41$ ,  $P = 0.003$ ), had 133 g more water ( $t_{17} = -2.99$ ,  $P = 0.008$ ), 210 g more wet lean mass ( $t_{17} = -3.31$ ,  $P = 0.004$ ) and 68 g more dry lean mass ( $t_{17} = -4.03$ ,  $P < 0.001$ ) than females. Wing chord of male eiders averaged 14 mm longer than females ( $t_{17} = -3.08$ ,  $P = 0.007$ ), heads were 10 mm longer ( $t_{17} = -4.55$ ,  $P < 0.001$ ) and culmen length was 6 mm longer ( $t_{17} = -5.72$ ,  $P < 0.001$ ). There were no differences in fat and feather mass, culmen width, or tarsus length between male and female eider (Table 2).

### **Structural Size of Eider**

The first principal component ( $PC1 = 0.894(\text{head}) + 0.831(\text{wing chord}) + 0.823(\text{body mass}) + 0.705(\text{culmen length}) + 0.616(\text{culmen width}) + .261(\text{tarsus})$ ) accounted for 52% of the total variance. The second principal component ( $PC2 = 0.868(\text{tarsus}) - 0.47684(\text{culmen width}) + 0.267(\text{culmen length}) + 0.132(\text{head}) - 0.163(\text{wing}) - 0.126(\text{body mass})$ ) accounted for an additional 19% of the total variance. Eider with higher loadings for the first principal component (PC1) had a larger head, wing and culmen, and were heavier, whereas those with higher loadings for the second principal component (PC2) had a longer tarsus and shorter culmen width. We used these

first 2 principal components in our predictive models to account for the contribution of body size to variation in body composition.

### **Predictive Models for Estimating Body Composition of Eider**

Deuterium-estimated total body water was strongly related to measured total body water (Fig. 2) although deuterium dilution overestimated measured total body water by  $13.30 \pm 0.73\%$  (8.63 – 20.86 %) as found in previous studies (Karasov and Pinshow 1998, Speakman 2001, Eichhorn and Visser 2008, McWilliams and Whitman 2013). The highest ranked model for predicting total body water included sex and deuterium-estimated total body water; however, sex was not a significant parameter in the model ( $f_{1,16} = 2.01$ ,  $P = 0.176$ ). Furthermore, the slope of the relationship between the measured and deuterium-estimated total body water for each sex was similar and the intercepts did not differ from zero ( $P > 0.20$  in all cases). We therefore excluded sex from the final model for predicting total body water (pwat) given estimated deuterium space (pwat =  $-97.5109 + .9571(\text{deutmw})$ ). This model predicted total body water within  $21.54 \pm 4.67$  g absolute error and  $1.90 \pm 0.45$  % relative error.

The best supported model for estimating lean mass (Model 1) of the 6 candidate models (Table 3) included deuterium-estimated body water, both of the principal components that described structural size, and sex. The best supported models without structural measures (Models 3 and 4) included deuterium-estimated body water and sex with the most parsimonious of the 2 models (Model 4) providing the lowest RMSE and lowest absolute and relative error of the 6 competing models.

The best supported models for estimating fat mass (Models 1 and 2) of the 6 candidate models (Table 4) included deuterium-estimated body water, sex and either

structural size or body mass, although Model 1 provided a much lower RMSE and among the lowest absolute and relative error of the 6 competing models. The predictive model developed using non-linear regression explained a significant amount of the variation in fat mass ( $R^2 = 0.936$ ), although this model produced less accurate estimates of fat mass (RMSE = 55.94 g, absolute error = 42.09 g, relative error = 25.93 %) than the best supported multiple linear regression models (Table 5).

### **Estimating Body Composition of Field-Caught Eider**

Given the results from the AIC model selection described above, we used the following predictive models for estimating fat and lean mass of field-caught eider: we estimated fat mass given deuterium-estimated total body water, body mass, and sex (Model 1 in Table 4), and we estimated lean mass given deuterium-estimated total body water and sex (Model 4 in Table 3). Two of the original 90 eiders had deuterium-estimated water levels that were biologically unreasonable (<50% or >80% of body mass), and 1 eider was lighter and another heavier than those used in the validation. Thus, we used 86 eiders to investigate body composition changes of male and female eider throughout the winter.

Body mass changed across the 3 winter periods ( $F_{2, 80} = 4.39$ ,  $P = 0.016$ ), differed between males and females ( $F_{1, 80} = 32.62$ ,  $P < 0.001$ ), and the interaction between sex and sampling period was not significant ( $F_{2, 80} = 0.93$ ,  $P = 0.399$ ). On average, male eiders ( $2048.3 \text{ g} \pm 18.7 \text{ g}$ ) were 153.0 g heavier than females ( $1895.3 \text{ g} \pm 15.2 \text{ g}$ ). Eiders in late winter ( $2045.6 \text{ g} \pm 25.9 \text{ g}$ ) were 132.0 g heavier than birds in early winter ( $1913.6 \text{ g} \pm 20.4 \text{ g}$ ) (Figure 3A).

Fat mass changed across the 3 winter periods ( $F_{2, 80} = 22.98$ ,  $P < 0.001$ ), did not differ between males and females ( $F_{1, 80} = 2.07$ ,  $P = 0.155$ ), and the interaction between sex and sampling period was not significant ( $F_{2, 80} = 1.09$ ,  $P = 0.3398$ ). On average, eiders had  $241.8 \pm$  g of fat during winter and eiders in late winter ( $311.4 \text{ g} \pm 16.9 \text{ g}$ ) averaged 133.4 g more fat than eiders in early winter ( $178.0 \text{ g} \pm 12.7 \text{ g}$ ) (Figure 3B).

Wet lean mass changed across the 3 winter periods ( $F_{2, 80} = 5.32$ ,  $P = 0.007$ ), differed between males and females ( $F_{1, 80} = 49.91$ ,  $P < 0.001$ ), although the interaction between sex and sampling period was significant ( $F_{2, 80} = 3.12$ ,  $P = 0.049$ ). On average, males ( $1687.0 \text{ g} \pm 17.2 \text{ g}$ ) had 146.2 g more wet lean mass than females ( $1540.8 \text{ g} \pm 18.0 \text{ g}$ ). Males in late winter ( $1695.5 \text{ g} \pm 24.1 \text{ g}$ ) did not differ from males in early winter ( $1716.0 \text{ g} \pm 36.7 \text{ g}$ ); however, females in late winter ( $1435.5 \text{ g} \pm 53.5 \text{ g}$ ) averaged 163.0 g less wet lean mass than females in early winter ( $1598.5 \text{ g} \pm 17.5 \text{ g}$ ) (Figure 3C). The sex and sampling period interaction was not significant when the female with the lowest wet lean mass during late-winter was removed from the analysis.

## **DISCUSSION**

### **Validation of the Deuterium Dilution Method for Estimating Body Composition of Eider**

We provide the first validation of the deuterium dilution method for indirectly measuring body composition of a sea duck, the American common eider. Deuterium dilution accurately estimated wet lean mass with a RMSE of 39.1 g, an absolute error of  $32.4 \pm 5.18 \text{ g}$  and relative error of  $2.0 \pm 0.4 \%$ , while fat mass was estimated with a RMSE of 43.0 g, an absolute error of  $35.9 \pm 5.6 \text{ g}$  and relative error of  $20.2 \pm 3.9 \%$  (Table 5). These predictive models required measurement of body mass, determining age

and gender of each bird, and estimating total body water using the deuterium dilution method. These models will enable biologists to obtain relatively accurate estimates of body composition without having to use direct lethal methods. Jamieson et al's (2006a) models for indirectly estimating total carcass lipid (fat) of northern common eiders required measures of body mass and structural size and estimated fat mass with RMSEs of 32.7-38.9 g compared to direct measures of fat mass with a RMSE of 14.6 g. In a validation of the deuterium dilution method for estimating body composition of barnacle geese, fat mass was estimated with a relative error of  $10.1 \pm 10.1$  % while fat free (lean) mass was estimated with a relative error of  $1.2 \pm 1.4$  % (Eichhorn and Visser 2008). Recently, McWilliams and Whitman (2013) used deuterium dilution to estimate fat and lean mass of 3 migratory passerines, with relative errors of  $26.36 \pm 18.6$  to  $34.13 \pm 10.25$  % for fat mass and  $1.96 \pm 0.70$  to  $5.31 \pm 1.55$  % for lean mass. Previously, Karasov and Pinshow (1998) used deuterium dilution to estimate lean mass of blackcaps (*Sylvia atricapilla*) with a relative error of  $6.7 \pm 1.2$  %. In summary, the relative errors of the models we developed to estimate wet lean mass (ca. 1-3%) and fat mass of eiders (ca. 20%) are within the range of those values reported by previous studies using deuterium dilution (1-5% and 10-34%, respectively).

### **Methodological Considerations**

Deuterium dilution and the associated predictive models that we presented should only be used to estimate body composition of eiders of the same sub-species (*S. m. dresseri*) during winter that are within the range of body masses used for the validation (1595 and 2298 g) because differences could exist between different sub-species or different populations (Castro and Myers 1990). Other validation studies will be required

to estimate body composition of female eiders during spring and summer because the physiological changes associated with preparations for reproduction, egg laying and incubation (Milne 1976, Korschgen 1977, Parker and Holm 1990) are unlikely to be accurately predicted by the models that we present.

Biologists should also carefully consider the instrument that they plan to use for measuring deuterium concentration in blood water because it influences the amount of deuterium that must be injected into eiders. If measuring deuterium concentration with an Isotope Ratio Mass Spectrometer (IRMS), approximately 1 ml of deuterium should be injected into each eider that range in body mass between approximately 1500-2500 g. If measuring with an Infrared Spectrophotometer (IRSPEC), approximately 3ml of deuterium should be injected to ensure the diluted concentration is accurately measured by the instrument. Measurement of deuterium concentration with an IRSPEC requires less sample preparation and is easier to accomplish, but the higher injection volume may be more difficult to successfully inject in field settings.

Our highest ranked models for estimating wet lean mass necessitate measuring body mass and taking structural measures of all eiders injected with deuterium. Future investigations of eider body composition during winter are likely to be carried out over water and in challenging field conditions making it difficult to accurately measure these structures in the field prior to release of captured eider. Our jackknife validation of models used to estimate wet lean mass showed no difference in the predictions of the top ranking model that included PC1 derived from structural measures and the model that only included sex and predicted total body water. We recommend that whenever possible, biologists should obtain structural measures from the eiders they capture;

however, in the event that taking structural measures is not practical, biologists should measure body mass and record sex in addition to carrying out a deuterium injection in order to be able to predict wet lean mass and fat mass given the models that we provide.

### **Size and Body Composition of Eiders in Southern New England**

As expected, we found gender differences in size and body composition of eiders, and that American common eiders wintering in southern New England were larger and heavier than northern common eider. We found males were heavier and had more total body water, and wet and dry lean mass than females. Males were also larger than females, with longer wing chords, culmen and head lengths whereas tarsus length and culmen width were similar between sexes. The wing chord, tarsus and culmen lengths that we reported are larger on average than those reported by Palmer (1976), but the differences were minor. The mean body mass of the eiders used in our study was 50 g heavier than the mean of 70 birds used to develop and 9 g less than the mean of 22 birds used to test body composition models for northern common eider (Jamieson et al 2006a). The eiders in our study had 17 g and 20.2 g more fat, 89 g and 41 g more water and were structurally larger (wing chords 22 mm longer, tarsus 5mm longer and head-bill lengths 12 mm longer) than those in Jamieson et al.'s (2006a) study. Our measures support knowledge of size differences between American and northern common eiders.

### **Body Composition Changes During Winter**

The observed increases in body mass of male and female eiders in late winter in southern New England are in contrast to the insignificant changes in body mass of male northern common eiders in Scotland (Milne 1976), although body mass of females in this paper significantly increased in late winter. Similarly, Guillemette et al. (1992) found



insignificant changes in body mass for male and females throughout the winter period; however, flock size partially explained body mass as those eiders sampled from large flocks (>300 individuals) had higher body masses than those from smaller flocks during early and mid winter. Changes in eider body mass during winter are variable within and between locations during winter and are likely related to local habitat conditions, disturbance and climatic events.

Male American common eider had more wet lean mass than females throughout winter which is similar to the gender differences in body protein reported in northern common eiders by Jamieson et al (2006b). The decrease in wet lean mass of female American common eider during late-winter that we documented was not observed in the northern subspecies (Milne 1976, Jamieson et al. 2006b) whereas all studies of common eider to date found that wet lean mass of males did not significantly change during winter (Milne 1976, Jamieson et al. 2006b, our study). Loss of wet lean mass during winter has been observed in other waterfowl (Ballard et al. 2006, Meissner et al. 2012) and may be related to local environmental conditions, different migration or breeding strategies.

In general, female and male American common eiders during winter in southern New England had more fat mass (mean 232 and 242 g, respectively) than eiders during winter in Maine (mean 175 g; Korschgen 1977), Scotland (females ~ 160 g, males ~ 170 g; Milne 1976), Quebec (males 17 - 170 g; Guillemette et al. 1992), and Greenland (females 205 g, males 221 g; Jamieson et al. 2006b, Merkel et al. 2006) although these comparisons do not account for body size differences. Male and female American common eider had significantly more fat in late winter than they did in early winter and this accounted for the majority of the increase in body mass over winter. Milne (1976)

also reported a significant increase in fat during winter for female northern common eider, although he found no increase in fat for males. Merkel et al. (2006) reported a decrease in fat for male and female northern common eiders. Many possibly explanations exist for the changes in body composition that we observed during winter.

Previous studies on waterfowl body composition dynamics suggest that body weights and reserves peak in early winter before decreasing throughout the winter, likely due to temperature or food availability (Peterson and Ellarson 1979, Blem 1990, Gates et al. 2001). Blem (1990) hypothesized that fat storage is linked to photoperiod and that during the shortest days birds would store the most fat in order to get through the longest nights. However, eiders in southern New England during winter did not follow these trends, possibly indicating that food availability was sufficient to maintain body reserves throughout the winter. Body reserves were likely not impacted by colder air temperatures as this period (October 2011- March 2012) was the warmest on record for southern New England (NOAA 2012). Eider are sensitive to hunting disturbance (Bell and Owen 1990) and hunting-related disturbance may have decreased time spent foraging and displaced birds from preferred foraging sites (Gaston 1991, Laursen and Frikke 2008, Merkel et al. 2009). This may have prevented eiders from attaining maximum reserve levels during early winter when hunting occurred, whereas thereafter eiders were able to increase their reserves. Additional studies over multiple years that measure hunting pressure, time budgets, environmental factors and body composition may provide further insight into the factors driving body composition changes of eiders in southern New England.

## **MANAGEMENT IMPLICATIONS**

Deuterium dilution provides field biologists and managers with an indirect method for accurately estimating the body composition of eider during winter. As an indirect method, deuterium dilution alleviates the need for killing the bird and eliminates the time consuming and complex total carcass analyses needed to obtain measures of total fat, lean mass and total body water of birds. Managers working to conserve eider populations in the southern portions of their range may use deuterium dilution to better understand the ecology of the Wellfleet Bay Virus, which may enable managers to predict the severity of die offs and the potential for population level impacts. Finally, as offshore wind developments become more prevalent in the coastal waters of the eastern United States, managers will be able to assess the potential impacts of habitat displacement by measuring changes in body composition of eiders given those reported here.

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Table 1-1. Number and percent of captured adult common eiders within certain body mass ranges, those that were injected with deuterium but not used in the validation (injected-only), and those 19 adult eiders selected for the validation study that involved developing predictive models for estimating body composition. All eiders were captured during winters 2011-2012 and 2012-2013 in Rhode Island and Massachusetts, USA.

Mass (g)	All adult eider <sup>a</sup>		Injected-only		Validation-only <sup>b</sup>	
	n	%	n	%	n	%
1,350-1,500	1	0.7	-	-	-	-
1,501-1,650	5	3.5	1	1.1	1	5.3
1,651-1,800	28	19.6	13	14.4	5	26.3
1,801-1,950	49	34.3	35	38.9	3	15.8
1,951-2,100	36	25.2	25	27.8	4	21.1
2,101-2,250	21	14.7	15	16.7	4	21.1
2,251-2,400	3	2.10	1	1.1	2	10.5

<sup>a</sup>Mass was not measured for 5 of the 148 adult eider that were captured.

<sup>b</sup>Two of the 21 eider that were originally selected for the validation study were later excluded because their estimated total body water was biologically unrealistic (see text).

Table 1-2. Body composition and morphometrics of 19 adult common eiders captured during the winters of 2011-2012 and 2012-2013 in Rhode Island and Massachusetts, USA, and used for the validation study that involved relating estimated and measured body composition. Values presented are the mean  $\pm$  standard error (SE), with the range given in parentheses.

Component	Sex		Test statistic	
	Males	Females	$t_{17}$	$P$
Body mass (g)	2075 $\pm$ 54.6 (1742-2298)	1795 $\pm$ 60.2 (1595-2030)	-3.41	0.003
Wet lean mass (g)	1731 $\pm$ 36.2 (1515-1949)	1521 $\pm$ 44.5 (1387-1765)	-3.31	0.004
Dry lean mass (g)	507 $\pm$ 10.6 (450-562)	439 $\pm$ 13.3 (400-502)	-4.03	< 0.001
Fat mass (g)	226 $\pm$ 36.6 (122-569)	162 $\pm$ 16.3 (108-256)	-1.40	0.178
Water mass (g)	1231 $\pm$ 28.5 (1065-1388)	1098 $\pm$ 34.1 (987-1263)	-2.99	0.008
Feather mass (g)	111 $\pm$ 6.3 (80-141)	96 $\pm$ 3.6 (77-108)	-1.91	0.073
Tarsus length (mm)	56 $\pm$ 1.1 (50-61)	54 $\pm$ 0.6 (51-56)	-0.93	0.366
Culmen length (mm)	60 $\pm$ 0.7 (56-64)	54 $\pm$ 0.7 (51-57)	-5.72	< 0.001
Culmen width (mm)	22 $\pm$ 0.2 (21-24)	22 $\pm$ 0.4 (20-23)	-1.97	0.065
Head length (mm)	135 $\pm$ 1.6 (127-145)	125 $\pm$ 1.4 (120-132)	-4.55	< 0.001
Wing chord (mm)	308 $\pm$ 3.1 (293-320)	294 $\pm$ 3.1 (285-306)	-3.08	0.007
<i>n</i>	11	8		

Table 1-3. Results of best fitting models for estimating wet lean mass of adult common eider captured in Rhode Island and Massachusetts, USA during the winters of 2011-2012 and 2012-2013 given deuterium-estimated body water, 2 principal components of structural size, sex, and body mass. Akaike information criterion corrected for small sample size ( $AIC_c$ ), difference in Akaike information criterion ( $\Delta AIC_c$ ) from top model, root mean square error of the prediction (RMSE g), absolute (Abs g) and relative errors (Rel %) are provided for each model.

Model	Variables	$AIC_c$	$\Delta AIC_c$	Error		
				RMSE (g)	Abs (g) (SE)	Rel (%) (SE)
1	pwat, PC1, PC2, sex	169.4	-	55.65	44.81 (7.78)	2.82 (0.53)
2	pwat, PC1, sex	176.0	6.6	51.31	41.83 (7.01)	2.63 (0.49)
3	pwat, mb, sex	184.1	14.7	63.13	43.53 (10.78)	2.73 (0.70)
4	pwat, sex	184.4	15.0	48.59	38.62 (6.95)	2.45 (0.49)
5	pwat, mb	194.2	24.8	64.76	43.75 (11.25)	2.75 (0.73)
6	mb	213.6	44.2	82.49	49.80 (15.50)	3.00 (0.96)

<sup>a</sup>*pwat* is predicted total body water given deuterium-estimated body water (figure 2;  $(pwat) = -97.5109 + .9571(deutmw)$ ); *PC1* is the first principal component; *PC2* is the second principal component; *mb* is body mass; and *sex* is 1 for female and 0 for male.



Table 1-4. Results of best fitting models for estimating wet fat mass of adult common eider captured in Rhode Island and Massachusetts, USA during the winters of 2011-2012 and 2012-2013 given deuterium-estimated body water, 2 principal components of structural size, sex, and body mass. Akaike information criterion corrected for small sample size (AICc), difference in AICc ( $\Delta$  AICc) from top model, root mean square error of the prediction (RMSE g), absolute (Abs g) and relative errors (Rel %) are provided for each model.

Model	Variables	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	Error		
				RMSE (g)	Abs (g) (SE)	Rel (%) (SE)
1	pwat, mb, sex	189.9	-	79.64	53.43 (13.92)	27.31 (5.82)
2	pwat, PC1, PC2, sex	191.2	1.3	122.34	72.80 (23.17)	34.48 (8.56)
3	pwat, mb	199.7	9.8	80.70	51.52 (14.64)	25.93 (6.09)
4	pwat, PC1, sex	200.5	10.6	118.41	72.48 (22.07)	35.07 (7.63)
5	pwat, sex	211.7	21.8	108.28	61.24 (21.05)	30.00 (6.72)
6	mb	215.8	25.9	88.43	52.01 (16.86)	23.26 (4.29)

<sup>a</sup>*pwat* is predicted total body water given deuterium-estimated body water (figure 2;  $(pwat) = -97.5109 + .9571(deutmw)$ ); *PC1* is the first principal component; *PC2* is the second principal component; *mb* is body mass; and *sex* is 1 for female and 0 for male.

Table 1-5. Final predictive models for estimating wet lean and wet fat mass of adult eiders given predicted water, 2 principal components of body size, body mass and sex constructed using measurements of all 19 validation eiders collected during winters 2011-2012 and 2012-2013 in Rhode Island and Massachusetts, USA. Root mean square error (RMSE g), absolute (Abs g) and relative (Rel %) errors  $\pm$  standard errors (SE) are provided as measures of accuracy.

Component	Model	Error		
		RMSE (g)	Abs (g) (SE)	Rel (%) (SE)
Wet lean	$y = 209.99 + 1.2427(\text{pwat}) + 10.2941(\text{PC1}) + 2.6881(\text{PC2}) - 39.1209(\text{sex})$	39.14	32.39 (5.18)	2.04 (0.36)
	$y = 169.45 + 1.2819(\text{pwat}) - 52.0223(\text{sex})$	39.40	32.03 (5.41)	2.02 (0.38)
Wet fat mass	$y = -99.4324 - 1.0591(\text{pwat}) + .7813(\text{mb}) + 32.0247(\text{sex})$	42.98	35.86 (5.58)	20.24 (3.94)

<sup>a</sup>*pwat* is predicted total body water given deuterium-estimated body water (figure 2;  $(\text{pwat}) = -97.5109 + .9571(\text{deutmw})$ ); *PC1* is the first principal component; *PC2* is the second principal component; *mb* is body mass; and *sex* is 1 for female and 0 for male.

Figure 1-1. Southern New England study area where 223 common eiders were captured as part of a body composition study conducted during winters 2011-2012 and 2012-2013 in Rhode Island and Massachusetts, USA.

Figure 1-2. Relationship between deuterium estimated water (g) and measured water (g) in adult common eider collected during winters of 2011-2012 and 2012-2013 in Rhode Island and Massachusetts, USA. Measured water was strongly and linearly related to deuterium estimated water (deutmw):  $(p_{wat}) = -97.5109 + .9571(\text{deutmw})$ ,  $R^2=0.931$  for 19 adult eiders used in the validation of the deuterium dilution method.

Figure 1-3. Comparison of (A) body mass (B) fat mass and (C) wet lean mass of 86 adult common eiders captured in Rhode Island and Massachusetts, USA during early winter 2011-2012, 2012-2013, mid and late winter 2011-2012. Box and whisker plots represent the 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles, the mean of each group is represented by a dashed line and the median is represented by the solid line. Sample sizes are given as numbers below each plot. Same letters above each time period indicate no significant difference determined using Tukey's multiple comparisons.

Figure 1-1.

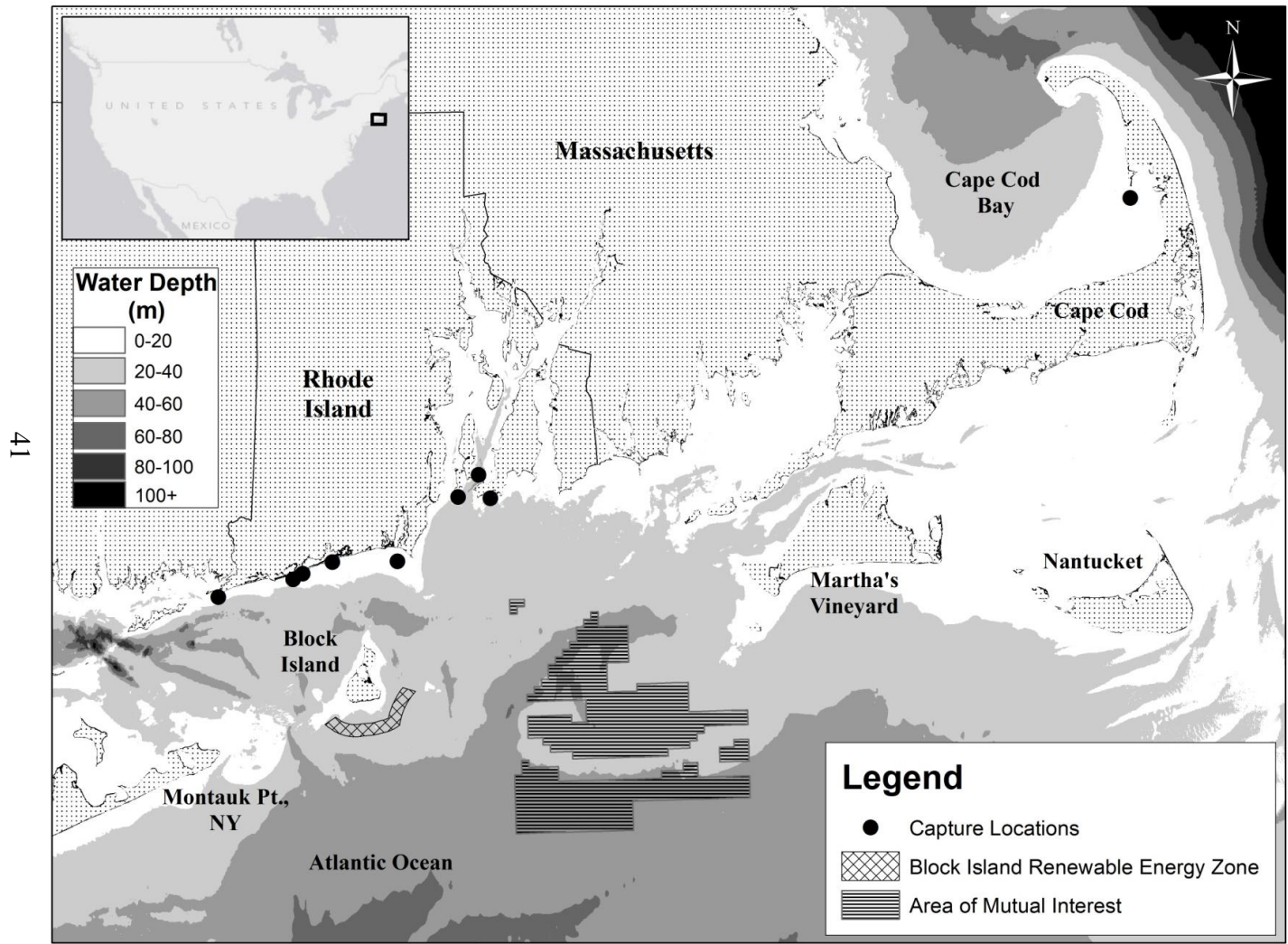
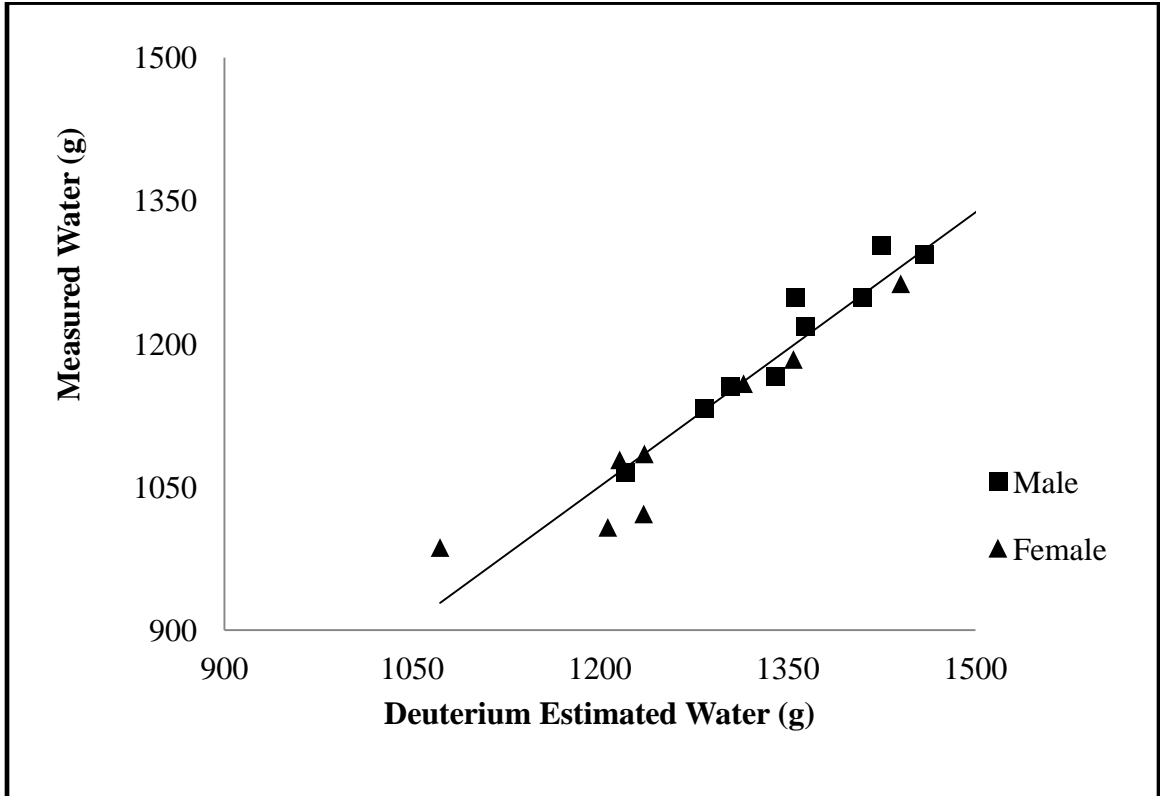
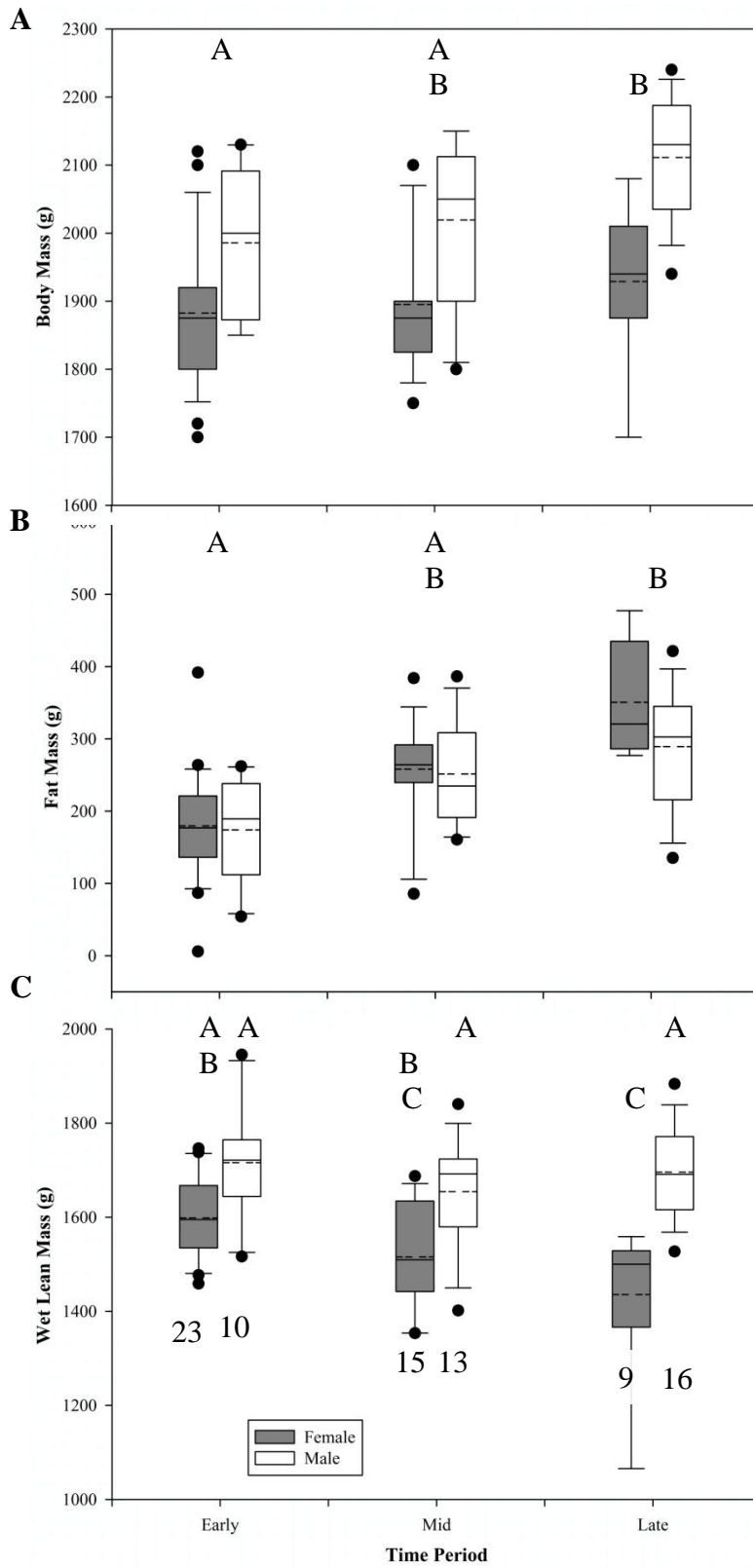


Figure 1-2.



**Figure 1-3.**



MANUSCRIPT - 2

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**Habitat Use and Movement Dynamics of Common Eiders in Southern New England  
Relative to Offshore Wind Energy Development**

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**Running Head.**—Beuth et al. • Common eiders and offshore wind

**ABSTRACT** There has been little documentation regarding the movement ecology and habitat selection of common eiders (*Somateria mollissima*) that spend the winter in southern New England. We used satellite telemetry to quantify migratory phenology, home range size, fidelity, and resource selection of 24 adult female eiders during winter in nearshore waters of Rhode Island, USA. Eiders spent on average 39% of their annual cycle during winter in southern New England during the winter of 2012-13. During spring migration, eiders took on average 16 days (range 2-47) and 20 days (range 1-61) in 2012 and 2013, respectively, to migrate from wintering grounds to summer areas, whereas fall migration averaged 47 days (range 7-115). Satellite-tagged eiders exhibited high site winter fidelity with 83% ( $n = 19$ ) returning to the study area the following winter. Eider roosted approximately 1 km farther offshore at night compared to diurnal foraging locations. Compared to other species of sea ducks, during winter eiders were relatively sedentary with mean individual core use areas that averaged 38.5 km<sup>2</sup> and utilization distributions that were 199.3 km<sup>2</sup>. Based on habitat selection models, eiders preferred habitats with shallower waters, that were closer to shore, that had relatively fine sediments and a higher probability of hard bottom. Only 3% of the study area was classified as having a high relative probability of use and 10% was classified as having a medium-high relative probability of use. There is potential overlap between eider habitat use and offshore wind energy development in southern New England; therefore future developments should avoid shallow, nearshore waters preferred by eiders to minimize potential impacts on this species.



**KEY WORDS.**—common eider, migratory phenology, offshore wind energy development, satellite telemetry, southern New England, winter fidelity, winter habitat use.

## **INTRODUCTION**

Understanding habitat use and movement ecology of wildlife is vital for effective conservation and management, yet difficult to ascertain for species that migrate long distances to inaccessible areas (Webster et al. 2002, Robinson et al. 2009). Research on the movements and habitat use of migratory waterfowl has led to the conservation and management of vital habitats throughout their annual cycle (Smith et al. 1989, Davidson and Stroud 1996) although such information about the movement ecology and resource selection of sea ducks is lacking (Robertson and Cooke 1999, Goudie et al. 2000, Johnsgard 2010). There is a pressing need to understand movement dynamics and habitat use patterns of North America's sea ducks because populations of many species are declining (Merkel 2004) and may face additional conservation challenges from a variety of factors including climate change (Lovvorn et al. 2009), offshore wind energy developments (OWED; RI Ocean SAMP 2010, Bureau of Ocean Energy Management 2012), disease (Ellis et al. 2010), and liberal hunting seasons (Caithamer et al. 2000, Raftovich et al. 2011).

Most studies of sea duck movement dynamics in North America have occurred on the Pacific Coast (Petersen et al. 1999, Iverson and Esler 2006, Phillips et al. 2006, Lok et al. 2008, De La Cruz et al. 2009, Opper and Powell 2009, Petersen 2009, Dickson 2012); whereas, less is known about their local and regional movement ecology on the Atlantic Coast (Mosbech et al. 2006, Zipkin et al. 2010, Loring 2012). Our current

understanding of the winter distribution, abundance, and habitat associations of sea ducks on the Atlantic Coast is somewhat limited because it is primarily based on sporadic aerial (Zipkin et al. 2010, Silverman et al. 2013) and land-based surveys (McKinney et al. 2006, Winiarski et al. 2011), and citizen-science counts (National Audubon Society 2010, New Jersey Audubon 2013) that were primarily conducted during daylight hours under favorable weather conditions. Therefore, on the Atlantic Coast, we know little about local and regional movement ecology throughout the annual cycle for most species of sea ducks. We also lack a detailed understanding of habitat preferences by sea ducks on their wintering grounds in the Atlantic region (but see Loring 2012).

One of the most abundant sea ducks using nearshore habitats in northeastern North America during winter is the common eider (*Somateria mollissima*) (hereafter eider; Silverman et al 2013), with two recognized subspecies: northern common eider (*S. m. borealis*) and American common eider (*S. m. dresseri*) (Goudie et al. 2000). Eiders are thought to be highly philopatric to their breeding grounds (Reed 1975, Robertson and Cooke 1999), and northern common eider exhibit high site fidelity to their wintering grounds (Merkel et al. 2006). Local fidelity is thought to be driven primarily by local prey abundance (Guillemette et al. 1996, Larsen and Guillemette 2000), but site fidelity to breeding and wintering grounds has never been studied for American common eiders that spend the winter in southern New England. Eiders generally inhabit nearshore waters with water depths up to 20m (Goudie et al. 2000) where they forage on blue mussels (*Mytilus edulis*), crustaceans and other benthic invertebrates typically associated with rocky sublittoral substrate (Ydenberg and Guillemette 1991). Available evidence suggests that eiders fly offshore to roost at night (Mackay 1890, Winiarski et al. 2011); however,

no research to date has accurately assessed nocturnal habitat use patterns, or documented the location of offshore roost sites in southern New England.

Assessing potential impacts of anthropogenic disturbances on seaducks has become increasingly important with the advent of OWED, although all such research to date has been conducted in western Europe where OWED has occurred. Anthropogenic disturbances associated with future OWED potentially threaten eiders wintering in southern New England, either through habitat displacement or direct mortality. Several small and large-scale OWED projects are proposed for the coastal waters of southern New England, with many others proposed or being explored along the Atlantic Coast of the United States (Musial and Ram 2010, RI Ocean SAMP 2010, Bureau of Ocean Energy Management 2012, New York Department of State 2013). In Europe, sea ducks have been displaced from preferred feeding habitats at the Nysted and Horns Rev 1 offshore wind facilities, Denmark (Petersen et al. 2006). There is some evidence that habitat displacement can be short-term, as the distribution and abundance of common scoters (*Melanitta nigra*) did not differ inside and outside the wind farm's footprint after approximately five years, however, the authors found no evidence that other species, including eiders had changed their distribution relative to the wind farm (Petersen and Fox 2007). Radar monitoring at Denmark's offshore wind farms has shown that wind turbines are a barrier to migratory movements of birds, causing most eiders to fly around the wind farm (Desholm and Kahlert 2005; but see Masden et al. 2009). Lastly, Larsen and Guillemette (2007) also documented significant behavioral shifts and avoidance of the wind turbines by eiders in Denmark.

The specific objectives of this study were to assess the movement dynamics of American common eider by: 1) using satellite telemetry to quantify movement patterns throughout the annual cycle of eider tagged during winter in southern New England, 2) determining site fidelity and utilization distributions of satellite-tagged eiders during winter in southern New England, 3) identify the biotic and abiotic factors associated with winter habitat selection of tagged eiders in southern New England, and 4) develop a spatially-explicit model of the probability of eider use for all nearshore and offshore waters of southern New England in relation to proposed OWED in the region. Studying the winter habitat use and movements of eiders in southern New England prior to the construction of OWED will allow biologists to make informed siting recommendations that could potentially minimize the effects of OWED disturbances on eiders.

## **STUDY AREA**

### **Southern New England**

Our study area included 6,405 km<sup>2</sup> of nearshore and offshore waters of the south-central New England continental shelf, which we define as the waters extending east from Fishers Island, New York to the western edge of Martha's Vineyard, Massachusetts, including the waters of Block Island and Rhode Island Sound (Figure 2-1). Water depths in Rhode Island and Block Island Sounds range from 0 to 65 m, with approximately 18.7% of the study area  $\leq$  20 m. Southern New England provides extensive habitat for eiders and other sea ducks that typically feed in water depths of 20 m or less (Goudie et al. 2000). Rocky reefs and scattered mussel beds occur throughout the sea floor off southern New England and provide eider excellent foraging opportunities for benthic invertebrates (Theroux and Wigley 1998) such as blue mussels (*Mytilus edulis*) and green

crabs (*Carcinus maenas*) (Loring et al. 2013), which are preferred food sources of eider (Ydenberg and Guillemette 1991). With the combination of habitat and foraging opportunities, this study area lies within one of the highest density areas of wintering sea ducks on the Atlantic Coast (Silverman et al. 2013).

## **METHODS**

### **Capture and Marking**

We used floating mist nets surrounded by decoys (Brodeur et al. 2008) to capture eiders during November and December 2011 ( $n = 139$ ). We deployed 3 pairs of mist nets (net size: 1.3 m x 18 m, 127-mm mesh) over near shore (<1 km) feeding locations from pre-dawn until 2-4 hrs after sunrise. Teams of 2-4 biologists in 6-7 m outboard skiffs closely monitored mist nets from approximately 100 m away. We immediately removed captured birds from mist nets, determined their age and gender based on wing plumage characteristics (Carney 1992), measured body mass with a Pesola spring scale ( $\pm 5$ g) and banded them using a United States Geological Survey size 7 aluminum butt-end leg band.

We selected the 26 heaviest adult female eiders (1650-2120 g) to receive an implantable satellite transmitter. Recently, Petersen et al. (2012) assessed winter site fidelity of Pacific common eider (*Somateria mollissima v-nigrum*) using a similar sample size (24 female and 1 male), and a minimum of 20 birds has been recommended for avian satellite telemetry studies; although this depends on project goals (Lindberg and Walker 2007). We selected only females because eiders form mixed gender flocks on the wintering areas (Campbell 1978, Guillemette et al. 1993, Systad et al. 2000) and Spurr and Milne (1976) found that 57% of female eiders are paired with males by mid-winter.

Therefore, we were confident that selecting only adult females would be representative of the movement dynamics of wintering male common eider in southern New England.

We used 44 g coelemic-implant Platform Transmitter Terminals (PTTs) equipped with external antennas (Microwave Telemetry Inc., Columbia, Maryland, USA) that were wrapped with sterile surgical mesh prior to surgery (Mulcahy 2001). Licensed veterinarians implanted a PTT into the abdominal cavity of each adult female eider, with the antenna protruding from the dorsal surface of the bird following procedures developed by Korschgen (1996). After surgery, eiders were housed using individual pet crates (48.26 cm x 31.75 cm x 26.04 cm ht), received subcutaneous fluids 3 hrs post-surgery as described by Ford et al. (2011), and were subsequently released at the capture location within on average 4 hr 28 min  $\pm$  17 min after PTT implants.

We programmed transmitters with a duty cycle of 4 hrs on, 24 hrs off for 118 duty cycles, which lasted until the end of winter (Season One). Thereafter transmitters switched to a duty cycle of 4 hrs on, 96 hrs off until the end of the battery life (Season Two), which was expected to be approximately 1-1.5 yrs. In order to minimize potential bias in habitat use associated with the trauma of surgery, we excluded the first 14 days of location data collected after release (Esler et al. 2000, Loring 2012), although when we calculated length of stay during the first winter we started with the release date. Collection of data used for home range estimation and habitat selection analyses began between 28 November and 25 December 2011 with a median date of 20 December 2011. The PTTs switched from the Season 1 duty cycle to the Season 2 duty cycle between 3 April and 5 May 2012, with a median date of 27 April 2012.

We conducted all methods with approval of the University of Rhode Island Institutional Animal Care and Use Committee (Protocol # AN 11-09-004).

### **Location Data**

We used a similar protocol described by Loring (2012) to process the satellite-telemetry data. Briefly, we used the Argos satellite-based location and collection system (Collecte Localisation Satellites 2011) to receive transmission signals from the eiders and processing centers reported accuracy for location classes (LC) 3, 2, 1 and 0, with accuracies of <250m, 250-500m, 500-1500m and > 1500m, respectively (Argos 2011). We did not assign location accuracy for LC's A and B, and LC Z was an invalid location. We used SAS 9.2 (SAS Institute, Inc., Cary, NC) to run the Douglas-Argos Filter to remove unlikely locations and retained the single location with the highest accuracy from each duty cycle for subsequent analyses. We used a hybrid filter to retain the best quality locations during winter and during migratory periods with longer movements (Douglas et al. 2012). We produced all maps, managed and analyzed telemetry data using ArcGIS 10.0 (Environmental Systems Research Institute, Inc. Redlands, CA), and used SAS 9.2 (SAS Institute, Inc., Cary, NC) to perform statistical analyses unless otherwise stated.

### **Length of Stay and Phenology**

We assessed duration of stay at the winter and summer areas as well as migratory phenology as outlined by De La Cruz (2009). In brief, we defined the first winter length of stay as the period of time between transmitter deployment and spring departure from the study area. The second winter length of stay was defined as the period between the fall arrival and spring departure date from the study area, and one day was added to the calculated length of stay to account for the possibility that the bird was on the study area

for part of the arrival and departure days. We defined fall arrival date as the median date between the first location within the study area and the previous location outside the study area during fall migration. We defined spring departure as the median date between the first location outside the study area during spring migration and the previous location within the study area.

Following De La Cruz et al. (2009), we used linear regression to model the relationship between body composition at the time of capture and transmitter implantation and wintering area departure date. We defined body composition as estimated water, fat and lean mass at the time of capture determined using deuterium dilution (see Chapter 1 for complete methods).

For length of stay on winter and summer areas and duration of migratory periods we present mean  $\pm$  SE. Arrival and departure dates are presented as mean (range).

### **Diurnal and Nocturnal Habitat Use**

To compare characteristics of diurnal and nocturnal locations, we analyzed distance to shore and water depth at locations of eiders that spent the entire winter 2011-12 in the study area. We used sunrise and sunset times obtained from the United States Naval Observatory for New Shoreham, Rhode Island (U.S. Naval Observatory 2013) to divide the day into 4 periods: dawn (1 hr before and after sunrise), dusk (1 hr before and after sunset), diurnal (between dawn and dusk), and nocturnal (between dusk and dawn) and assigned each location to one of the periods (Loring 2012).

We selected the best quality locations (LC 3 [accuracy <250m] and LC 2 [250-500m]) for each day using the Douglas-Argos filter (Douglas et al. 2012) for each eider during the winter 2011-12. We used the Euclidian Distance tool within Arc GIS Spatial



Analyst to calculate a distance (km) to shore grid. Distance to shore for each cell within the raster grid is calculated as the distance between the cell midpoint and the closest vector of the Northeastern United States State Boundary Line (1:24,000; Connecticut Department of Energy and Environmental Protection (CT DEEP) 2006). We overlaid diurnal and nocturnal point locations onto the distance to shore grid and extracted distance values for each point. We used the National Oceanic and Atmospheric Association (NOAA) U.S. Coastal Relief Model from the NOAA National Geophysical Data Center to obtain 3 arc second resolution bathymetry data (m) (NOAAa 2012) at each diurnal and nocturnal point. We averaged diurnal and nocturnal distance to shore and water depth values for each individual bird (Table 2-3) and used quantile-comparison plots to assess the distribution of the data. Mean values for diurnal distance to shore were not normally distributed, thus we used Wilcoxon signed rank tests for paired data to test for differences. Values for distance to shore and water depth at diurnal and nocturnal locations and differences between diurnal and nocturnal locations are reported as mean ( $\pm$  SE).

### **Winter Utilization Distributions**

We calculated utilization distributions within our study area by first randomly selecting 50 locations from the highest quality (LC 3 and LC 2) locations for each individual. We excluded the first 14 days after initial deployment to remove any effects due to recovery from surgery on eider movements. We calculated individual kernel utilization distributions using the Gaussian kernel and least squares cross validation bandwidth estimator using Geospatial Modeling Environment (GME; Beyer 2012). Using GME, we then pooled the 50 locations for eiders that spent the entire 2011-12 winter within the

study area (1,050 locations total) and estimated individual and composite 95% kernel utilization distributions and 50% kernel core-use areas. We removed locations on land because eiders are not known to occur inland during winter, thus we assumed these locations were errors. Finally, we then calculated total surface area (km<sup>2</sup>) of the individual and composite 95% kernel utilization distributions and 50% kernel core-use areas.

We report the area of individual core use areas and utilization distributions and the percent of time spent inside or outside of the study area as mean  $\pm$  SE.

### **Habitat Selection During Winter**

We used the composite 95% kernel utilization distributions (available) and 50% kernel core use areas (used) to assess eider habitat selection during winter 2011-12. We were interested in quantifying habitat selection for the entire 24-hr period; thus, we combined diurnal and nocturnal locations for this analysis. Following Loring (2012) we used habitat data in raster format that we resampled to a cell size of 250m<sup>2</sup> (6.25 ha). To estimate the distance to shore for randomly selected used and available cells, we used Spatial Analyst in Arc GIS to calculate the Euclidian Distance (m) of each raster cell to the nearest part of the Northeastern United States State Boundary Line (1:24,000, CTDEEP 2006). To estimate water depth at used and available cells, we used the National Oceanic and Atmospheric Association (NOAA) U.S. Coastal Relief Model from the NOAA National Geophysical Data Center to obtain 3 arc second resolution bathymetry data (NOAA 2012a). To estimate sediment grain size, we obtained sediment size (phi scale) from predictive models for the study area (Poti et al. 2012). To quantify probability of hard

bottom, we used a kernel-based probabilistic model of hard-bottom occurrence developed by Loring (2012).

We investigated use of habitat components within the home range of eiders (third-order resource selection [Johnson 1980]), by quantifying habitat characteristics within core areas and comparing them to those within the complete utilization distribution for winter 2011-12 (Sampling Protocol-A; Manly et al. 2002). We used the *genrandompnts* function in Geospatial Modeling Environment (Beyer 2012) to generate the maximum number of random points within the composite 95% utilization distribution and the 50% core use area, with a minimum separation of 500m. We removed randomly-selected points that occurred on land (used:  $n = 35$ , available:  $n = 125$ ) by clipping the point dataset to the Northeast United States State Boundary Line (CT DEEP 2006). Values for sediment grain size were omitted for 175 of the available points because of incomplete spatial coverage of the sediment grain size dataset. We did not to remove points from the used sample because resource selection functions (RSF) are robust to contamination (Johnson et al. 2006). Overall, we used 2,839 points within the available area (17% of total area) and 580 points within the used area (19% of total) for analysis of resource selection. We present mean  $\pm$  SE when comparing habitat characteristics of used and available samples.

Using SAS, we assessed multicollinearity by generating variance inflation factors (VIF) using the *proc reg* function and used Pearson correlation coefficients to assess relationships amongst pairs of habitat variables using *proc corr*. Correlation between pairs of habitat variables was weak to moderate with all values  $\leq 0.619$  and VIF values

were  $\leq 2.79$ . Following Loring (2012) we used logistic regression described in Manly et al. (2002) to generate beta coefficients for the exponential RSF model.

We generated 17 *a priori* models using combinations of habitat variables to predict the beta coefficients for the exponential RSF model and report Akaike Information Criterion values for each model. We ranked models using differences in Akaike Information Criterion ( $\Delta$  AIC) and calculated relative likelihood values and Akaike weights which we used to evaluate the relative likelihood of each candidate model (Burnham and Anderson 2002).

We predicted relative probability of habitat use by eiders for 6,212 km<sup>2</sup> of the 6,405 km<sup>2</sup> that composed the study area using the RSF derived from our highest ranked logistic regression model. We were unable to predict probability of use for 193 km<sup>2</sup> of the study area due to incomplete spatial coverage of sediment grain size habitat data. Our RSF model followed the format of *equation 5.11* in Manly et al. (2002):

$$W(x) = \exp(\beta_1 x_1 + \dots + \beta_p x_p)$$

Within Arc GIS we used geometrical interval to classify the distribution into 6 classes to represent relative probability of use from unlikely to high.

To assess the predictive performance of the resource selection function model we used a *k*-fold cross validation technique modified by Johnson et al. (2006). For the validation, we used 10 randomly selected high quality (LC 3 and LC 2) winter 2011-12 locations from each of the eiders that were not included in the 50 randomly selected locations used to derive individual and composite core use areas and utilization distributions. We removed locations that occurred over land as well as in areas where probability of use was not predicted due to incomplete spatial coverage of the data which

resulted in a mean of  $9 \pm 0.25$  (range = 7 – 10) locations per bird. We conducted a Chi-square analysis of observed and expected proportion of locations within each relative probability of use class of the resource selection function model. We also used linear regression to compare the observed and expected proportions and concluded that the model was proportional to the probability of use if the regression line had a slope significantly different from 0 but not significantly different than 1 and the intercept was not significant different than zero (Johnson et al. 2006). We also computed Lin's coefficient of concordance to assess the fit of the resource selection model to actual use by eiders.

### **Site Fidelity**

We quantified site fidelity between winter 2011-12 and winter 2012-13 by first determining the number of eiders that returned to the study area. We then assessed the number of winter 2012-13 locations that were within an individual's 2011-12 core use area (50%) and utilization distribution (95%). We also quantified the number of an individual's 2012-13 locations that were within the 2011-12 composite core use area and utilization distribution. We only used locations assigned accuracy ratings of LC3 (<250 m) and LC 2 (250-500 m) to be consistent with the quality of the locations used to develop the core use areas and utilization distributions.

### **Body Composition and Wintering Ecology**

We used the deuterium dilution method to estimate water, fat and lean mass of 21 of 26 eiders at the time of capture and before transmitter implantation (see Chapter 1 for complete methods). We did not estimate body composition of 4 eiders because harsh field conditions made deuterium injections difficult to complete and 1 additional eider was

excluded because its' deuterium estimated water was 83.4 % which is biologically unlikely (Karasov and Pinshow 1998). We then assessed whether body composition at the time of capture influenced subsequent movements. We used linear regression to model the relationship between body composition at the time of capture and distance from capture location 30 days post-deployment.

When giving body composition results we present mean  $\pm$  SE (range) for body composition components and distances moved.

## **RESULTS**

### **Transmitter Performance**

Two transmitters failed early in the study (after 1 and 39 duty cycles) and were excluded from subsequent analyses. We collected sufficient data on 24 eider for the entire first winter (2011-12) period and 15 transmitters provided location data through the termination of data collection (mid Jul 2013) (Table 2-1). Overall, the 24 eider with transmitters were located on average 196 times and 90% of these locations had the highest accuracy (LC 3) or second best accuracy (LC 2) (Table 2-1). Hunters shot 2 of the eiders with transmitters, ending data collection after transmitting 169 (PTT 112413) and 174 (PTT 112417) usable locations. One eider (PTT 112420, 190 locations) was found dead and autopsy determined that the eider died from severe coelomitis caused by ingestion of a fish hook (Dr. Jennifer Ballard, pers. comm.). Six transmitters did not transmit up to mid-July 2013 (PTTs 112416, 112419, 112421, 112422, 112426, 112433) apparently due to exhaustion of battery power after transmitting between 157 and 208 usable locations (Table 2-1).

### **Annual Movements and Summer Areas of Eiders Tagged in Southern New England**

Twenty-one adult females spent the entire first winter (2011-12) from deployment to spring migration in the study area, and length of stay was  $128 \pm 3$  days (Table 2-2). Departure from the study area in spring was 4 April 2012 (range = 17 Mar to 13 Apr). During spring migration in 2012, eiders took  $16 \pm 3$  days (Table 2-2) to migrate to 4 distinct summer areas from our study area. Arrival to the summer areas was 19 April 2012 (range 21 Mar to 20 May 2012). Eiders wintering in Rhode Island waters migrated to 4 separate potential breeding or summering areas, which included: Maine, USA ( $n = 9$ ), St. Lawrence Estuary ( $n = 4$ ), Gulf of St. Lawrence ( $n = 4$ ) and Nova Scotia ( $n = 4$ ), Canada (Figure 2-1; Figure A-2-1).

One of 3 eiders that did not spend the entire 2011-12 winter in the study area left Chatham, Massachusetts on 18 March and migrated north, through the Bay of Fundy, around Quebec and into the St. Lawrence Estuary before moving to Maine on the 11 June 2011, where it spent the remainder of the spring and summer 2012 period. The other 2 eiders that did not spend the entire 2011-12 winter in the study area spent the spring and summer of 2012 in Maine ( $n = 1$ ) or Nova Scotia ( $n = 1$ ).

Movement phenology between winter and summer areas was generally similar among the four distinct potential breeding locations (Figures 2-2A, 2-2B). Eiders spent  $168 \pm 10$  days (Table 2-2) on the summer areas and departed for fall migration on 21 October 2012 (range = 27 Aug to 28 Dec). Eider took longer during fall migration ( $47 \pm 9$  days; Table 2-2) to move between summer areas and their wintering areas than during spring migration ( $16 \pm 3$  days and  $20 \pm 5$  days for 2012 and 2013, respectively). Eighteen of the 21 eiders that spent the winter of 2011-12 in the study area returned to the study area for the winter of 2012-13. Two eiders stopped before reaching the study area and

spent the winter of 2012-13 outside of the study area, and 1 transmitter failed during fall migration. One of the 3 eiders that did not spend the entire 2011-12 winter in the study area returned for winter 2012-13 and thus was included in summer 2012 departure, fall 2012 migration and winter 2012 arrival date calculations. For the 19 eiders that returned to the study area during winter 2012-13, the arrival date was 15 November 2012  $\pm$  8 days (range = 1 Sep 2012 to 31 Jan 2013).

During winter 2012-2013, 2 eiders were shot, 1 was found dead, and transmitters on 2 eiders failed while on the study area. The 14 eiders that transmitted data for the entire 2012-2013 winter spent 141  $\pm$  10 days (Table 2-2) in the study area and departed for spring migration on 4 April 2013  $\pm$  3 days (range = 18 Mar - 20 Apr 2013). The 14 eiders that departed the study area in spring 2013 arrived on their summer area on 23 April 2013  $\pm$  4 days (range = 30 Mar - 23 May 2013). The spring 2013 migratory period was on average 20  $\pm$  5 days (Table 2-2). For summer 2013, the 14 eiders still transmitting location data returned to the same summer area that they used during 2012.

In 2013, the eider that had made an unusual movement in 2012 before settling in Maine flew directly to the same location in Maine that it settled at during summer 2012. The other 2 eiders that did not spend the entire 2011-12 winter in the study area were philopatric to the same summer locations in 2013.

### **Diurnal and Nocturnal Habitat Use**

Common eider that spent the winter in the Rhode Island study area ( $n = 21$ ) were accurately located (LC2 or LC3) 30  $\pm$  1.5 (range 13-40) times during the day and 42  $\pm$  1.7 (range = 33 - 57) times at night during winter 2011-12. Distance to shore at diurnal locations (0.9  $\pm$  0.12 km) was 0.92 ( $\pm$  0.11) km closer to shore than nocturnal locations



( $1.8 \pm 0.15$  km) ( $V = 1$ ,  $P < 0.001$ ) (Table 2-3). Median difference for distance to shore was 1.01 km. Water depth at diurnal locations ( $9.4 \pm 1.01$  m) was 6.35 ( $\pm 1.16$ ) m shallower than at nocturnal locations ( $15.8 \pm 0.96$  m) ( $V = 219$ ,  $P < 0.001$ ). Median difference for water depth between diurnal and nocturnal locations was 6.26 m. We combined diurnal and nocturnal locations for subsequent analyses because the mean difference in distance to shore did not exceed the potential 1km of error and because the core use, utilization distributions, and habitat use were most useful if estimated over a 24-hr period.

### **Winter Utilization Distributions**

*Individuals within study area.*—We delineated individual core-use areas (50% kernel) and utilization distributions (95% kernel) for the 21 adult female eiders that remained in the study area for the entire 2011-12 winter and for 3 adult females that left the study area during winter 2011-12. Of the 1,050 randomly selected locations used to derive utilization distributions and core-use areas for these 21 eiders, 79% were classified as LC 3 and 21% were LC 2. Seventeen of these eiders had a single core-use area that was  $38.5 \pm 7.9$  km<sup>2</sup> whereas four eiders had two core-use areas (Table 2-4). Individual 95% utilization distributions for these 21 eiders were  $199.3 \pm 32.7$  km<sup>2</sup> (Table 2-4). Six eiders had a single, continuous utilization distribution whereas 15 eiders had 95% utilization distributions that were composed of 2-4 separate areas (Table 2-4).

*Composite.*—We also delineated a composite core-use area (50% kernel) and utilization distribution (95% kernel) for the 21 adult female eiders that spent the entire post-deployment period in the study area. The composite core-use area was 191.2 km<sup>2</sup> and the composite utilization distribution was 1042.1 km<sup>2</sup> (Figure 2-3). The composite core-use

area and utilization distribution encompassed much of the variance in individual core use areas and utilization distributions (Figure A-2-2) as shown by the location of the centroids of the 21 individual core use areas (Figure 2-3).

*Individuals outside study area.*—Three eider spent  $59 \pm 17$  % of the 2011-12 winter period outside the study area. Core-use areas and the utilization distributions for these eiders were  $295.2 \pm 12.7$  km<sup>2</sup> and  $1859.1 \pm 330.8$  km<sup>2</sup>, respectively (Table 2-4). Two of these 3 eiders had a single core-use area, whereas the other eider had 2 separate core-use areas (Figure 2-4). Of the 150 randomly selected locations used to derive utilization distributions and core areas of these 3 eiders, 81% were classified as LC 3 and 19% as LC 2 locations.

### **Habitat Selection During Winter**

During winter 2011-12 eider core use areas were shallower, closer to shore, with a finer sediment grain size, higher probability of hard bottom, more slope and increased roughness compared to habitat in the available area (Table 2-5). The top 5 logistic regression models of eider habitat use had a  $\Delta$ AIC of  $<3$  and the top 3 were within 2 AIC values (Table 2-6). Of the top 3 competing models, we chose the most parsimonious as the top-ranked model. The top ranked logistic regression model contained water depth, distance to shore, sediment grain size and probability of hard bottom and had an Akaike weight of 0.40. The  $\beta$  coefficients were negative for the intercept, water depth and distance to shore whereas sediment grain size and hard bottom probability were positive (Table 2-7).

The resource selection function calculated values between  $<0.001$  and 14.33 for each resource unit within the study area. Using Geometrical Interval within ArcGIS, we

classified probability of use as high (4.36-14.33), medium-high (1.32-4.36), medium (0.40-1.32), medium low (0.11-0.40), low (0.03-0.11) or unlikely (<0.001-0.03) (Figure 2-5).

Within the 6,212 km<sup>2</sup> study area, 3,451.5 km<sup>2</sup> (55.6%) was classified as unlikely used, 695.1 km<sup>2</sup> (11.2%) as low probability of use, 602.4 km<sup>2</sup> (9.7%) as medium-low probability of use, 650.4 km<sup>2</sup> (10.5%) as medium probability of use, 620.6 km<sup>2</sup> (10.0%) medium-high probability of use, and 191.7 km<sup>2</sup> (3.1%) as high probability of use (Figure 2-5). Approximately 0.81 km<sup>2</sup> (2.4%) of the Block Island Renewable Energy Zone (BI REZ) was classified as medium-high probability of use, 20.75 km<sup>2</sup> (61.3%) as medium probability of use, and 12.31 km<sup>2</sup> (36.3%) as medium-low probability of use by eiders. It was unlikely that eiders would use any of the offshore waters where the large Rhode Island/Massachusetts Area of Mutual Interest (RI-MA AMI) federal lease blocks are located.

Validation of the resource selection function model showed good fit between predictive relative probability of use and actual use ( $\chi^2 = 0.1607$ ; d.f. = 5;  $P = 0.9995$ ,  $R^2 = 0.847$ ; Figure 2-6). Lin's coefficient of concordance also supported good fit between predicted relative probability of use and actual use ( $\rho_c = 0.919$ ).

### **Site Fidelity**

Of the 20 eiders that spent the entire 2011-12 winter in the study area, 90% ( $n = 18$ ) were site faithful and returned to the study area in 2012-13, whereas 2 spent the 2012-13 winter in Cape Cod Bay, Massachusetts. One of the 3 eiders that spent considerable time outside of the study area in 2011-12 returned to the study area for 2012-13 winter. In total, 82.6 % (19 of 23) of eiders that were still transmitting data at the start of winter

2012-13 returned to the study area. Of the 415 locations (LC 2 and LC 3 only) collected from the 19 eider during the winter of 2012-13, 50.6 ( $\pm$  12.2) % were located within the individual's winter 2011-12 core use area and 71.8 ( $\pm$  16.6) % of locations were within the individual's winter 2011-12 composite utilization distribution. Overall, 28.2 ( $\pm$  7.6) % of winter 2012-13 locations were outside of an individual's 2011-12 core use areas and utilization distribution. Compared to fidelity to an individual's core use area and utilization distribution, eider locations during winter 2012-13 showed very high fidelity to the composite core use area and utilization distribution developed from the 21 eiders that spent the entirety of winter 2011-12 in the study area. Overall, 75.9 ( $\pm$  11.8) % of winter 2012-13 locations were within the winter 2011-12 core use area and 96.4 ( $\pm$  16.0) % of locations were within the winter 2011-12 composite utilization distribution (Figure 2-7). Only 3.6 ( $\pm$  2.2) % of winter 2012-13 study area locations were outside of the composite core use area and utilization distribution developed from 21 eiders for winter 2011-12.

### **Body Composition and Movements of Eiders**

Mean body mass of all 26 adult female eiders implanted with a transmitter was 1856  $\pm$  22.4 g (1650-2120 g). Body composition of 21 of these eiders included 180  $\pm$  17.3 g (5.8 - 392.9 g) of fat and 1596  $\pm$  18.0 g (1459-1746 g) of wet lean mass. Twenty of these 21 eiders (one failed transmitter) moved on average 19.0  $\pm$  7.31 km (0.06-129.6 km) away from their capture and deployment location by 30 days post-deployment. We found no relationship between the body composition of eiders prior to transmitter implantation and distance moved from deployment location at 30 days ( $R^2 < 0.05$ ,  $P = 0.33$ ). Eider that spent the entire 2011-12 winter in the study area ( $n = 19$ ) and that had less wet lean mass

at capture tended to depart later from the winter area in spring than eider with more wet lean mass at capture (adjusted  $R^2 = 0.18$ ,  $P < 0.05$ ). There was no significant relationship between body mass at capture and date of departure from the wintering area (adjusted  $R^2 = 0.02$ ,  $P = 0.25$ ) and no significant relationship between fat mass and date of departure (adjusted  $R^2 = -0.05$ ,  $P = 0.69$ ).

## **DISCUSSION**

### **Effects of Satellite Transmitters on Survival and Behavior of Eider**

Most adult female eiders (92%, 24 of 26 birds) tagged with satellite transmitters between 14 Nov and 11 Dec 2011 survived the first winter (up to Apr 2012). The temperature sensors indicated a normal internal body temperature during the last duty cycle of the 2 eider that did not provide location data up until April 2012, so we assumed the transmitters failed for these 2 eiders. Previous studies of sea ducks using satellite telemetry have documented varying mortality rates associated with implantable satellite transmitters. Black scoters (*Melanitta americana*) tagged during spring migration in 2009 and 2010 as part of an Atlantic Coast migration study experienced 10% mortality within the first 60 days following transmitter implantation (Sea Duck Joint Venture 2012), whereas Loring (2012) had nearly 50% mortality within the first 2-3 weeks after transmitter implantation for a group of mostly hatch-year black scoters tagged during winter 2010. Rosenberg and Petrula (2000) reported surgery-related mortality of 39% for black scoters in Alaska. Of 118 long-tailed ducks (*Clangula hyemalis*) implanted with satellite transmitters in the Atlantic Flyway during winters 2009-2012, 42% died or stopped transmitting within the first 60 days (Sea Duck Joint Venture 2012). Low mortality rates for eider during winter 2011-12 of this study is likely the result of several

factors including 1) selecting adult eiders heavier than 1650g and so presumably in good condition and able to tolerate and carry 44 g transmitters and 2) temperatures during the winter of 2011-12 were among the mildest ever recorded (NOAA 2012b).

Satellite transmitters play a critical role in studying sea duck ecology; nonetheless, the potential negative effects of implanted transmitters on behavior and the interpretation of the movement dynamics must be considered. Latty et al. (2010) documented slower descents and ascents and longer duration of foraging dives of captive eiders implanted with PTTs compared to the same eiders before surgery. In contrast, Guillemette et al. (2002) recorded no differences in reproductive activities between treatment and control eiders a year after implantation of data loggers that were about 2/5 the size of surgically implanted PTTs. Korschgen et al. (1996) used captive mallards to evaluate the effects of implanted transmitters and found no behavioral or physiological effects. Iverson et al. (2006) recommended coelomically-implanted transmitters for long-term satellite telemetry studies because they were better retained by scoters and surgery-related mortality was no higher than mortality rates of scoters outfitted with a transmitter not requiring surgery. Fast et al. (2011) documented minor short-term behavioral changes among 17 female eiders implanted with satellite transmitters such as walking with a limp; however, the same birds resighted the following year were no longer limping. In addition, Fast et al. (2011) found lower survival during the first year and no differences in survival rate thereafter.

Although we did not detect any mortality of eiders that was directly related to transmitters, we documented one eider foraging at a nearshore location with considerable amounts of ice on the external antenna (J. Beuth, personal observation). Ice retention

could increase drag when diving to forage, thus increasing energetic costs and decreasing profitability. Ice retention has never before been documented even in colder arctic climates (D. Mulcahy, personal communication). Re-sighting sea ducks with implanted transmitters is likely rare due to the harsh and often times inaccessible locations that they inhabit, therefore it may be impossible to determine the true frequency and significance of ice build-up such as we observed. During field work, we recaptured an eider implanted with a transmitter earlier in the winter that gained approximately 150 g since original capture and surgery. While some of the weight increase could be attributed to presence of scar tissue (Korschgen et al. 1996), all indications were that the bird was healthy and weight gain was more likely to be attributed to addition of energy stores.

### **Transmitter Duty Cycles and Documenting Fine-Scale Habitat Use of Sea Ducks**

Biologists have used a variety of duty cycles to investigate sea duck movement dynamics (e.g., Petersen and Flint 2002, De La Cruz et al. 2009, Dickson 2012) in part because of different goals of each study. Our study aimed to collect detailed location data in order to quantify habitat use during winter 2011-12; therefore, we used a 4 hr on, 24 hr off duty cycle to provide adequate number of locations during the winter period. In comparison to black scoters implanted with satellite transmitters programmed with the same 4 hr on, 24 hr off duty cycle in Rhode Island during December 2010, we obtained higher percentage of high quality (LC 3 and LC 2) telemetry locations (89.4%) which enabled us to reduce the error associated with poorer quality locations and make more accurate assessments of home range sizes and habitat use. Transmitters implanted in black scoters captured in New Brunswick, Canada had a 2 hr on, 72 hr off duty cycle which resulted in only 49% of randomly selected locations being accurate enough (LC2 and LC3) to assess habitat

use during winter; however, these longer off-duty cycles allowed the transmitters to provide data for approximately 2.5 years (Loring 2012). Research such as ours that investigates fine-scale habitat use of sea ducks requires more frequent, high-quality locations and, at least for black scoters and eider, the 4 hr on period provided more high-quality locations than the 2 hr on period for seaducks during winter in southern New England.

### **Body Composition and Movements of Eiders**

We found that eiders with less wet lean mass when transmitters were implanted departed later during spring migration than birds with more wet lean mass. Female eiders are known to rely on internal energy stores for the entire egg laying and incubation process (Korschgen 1977), thus it may be beneficial for those female eiders with less wet lean mass to remain on the wintering areas longer to avoid unfavorable conditions on the summer areas (Mosbech et al. 2006) and so to accumulate adequate nutrient stores for reproduction. We were unable to determine if our eiders nested, as a result the relationship between date of departure for spring migration and body composition should be interpreted with caution. It is also possible that the surgically-implanted transmitter had more of an effect on eiders with less wet lean mass at implantation, thus delaying their migration. Nevertheless, our eiders had high survival and showed strong fidelity to their wintering areas, therefore we have little reason to believe that the presence of a transmitter significantly impacted the timing of migratory movements. Future research could investigate the relationship between body composition during early winter, effects of transmitters and subsequent initiation of spring migration.

### **Length of Stay and Migratory Phenology**



Eiders in this study spent about 39% of the annual cycle within the southern New England study area (Table 2-2) which was slightly shorter than the winter length of stay reported for other sea ducks. For example, length of stay was 50% of the annual cycle for black scoters wintering in southern New England (Loring 2012), king eiders (*Somateria spectabilis*) wintering in the Bering Sea, Alaska spent approximately 44% of the annual cycle on their wintering area (Oppel et al. 2008), and Pacific common eiders (*Somateria mollissima v-nigrum*) wintering in the Bering Sea had a median length of stay of approximately 40% of the annual cycle (Petersen et al. 2012). Winter length of stay may vary between species and locations possibly due to climatic conditions, food availability, and migration strategies; however, our study was not designed to assess these factors. Knowing the average length of stay allows sea duck managers to better quantify the potential impacts of habitat degradation and the additional energetic costs from disturbances such as hunting and OWED.

The migration chronology during spring and fall that we documented corresponded with timing estimates developed by Winiarski et al. (2011) from land-based surveys. In addition, these departure and arrival times were relatively synchronous regardless of summer destination (Figure 2-2A, 2-2B). The duty cycles of transmitters in eider provided relatively few locations during spring and fall migrations and so our estimated durations of migration should be viewed with caution. In general, the average duration of spring migration that we report ( $16 \pm 3.4$  and  $20 \pm 4.7$  days during 2012 and 2013, respectively) is shorter and the fall duration longer ( $47 \pm 9.3$  days during 2012) than those reported for other eiders. Northern common eiders breeding in arctic Canada and West Greenland had average spring and fall migratory durations of  $27.3 \pm 9.8$  and

16.1 ± 18.7 days, respectively (Mosbech et al. 2006). Similarly, king eiders in Alaska averaged 62 ± 24 days for spring migration whereas 32% of the eiders completed fall migration within 2 weeks and 60% spent 3 or more weeks on fall migration.

One working hypothesis to explain the shorter spring migration duration of the more southerly wintering *S. m. dresseri* common eiders compared to the northerly wintering *S. m. borealis* common and *S. m. spectabilis* king eiders may lie in the foraging strategies of females. Guillemette (2001) found that *dresseri* females spend more time feeding than males prior to spring migration and enter a state of hyperphagia; whereas *borealis* females do not significantly increase time spent foraging prior to spring migration possibly because weight increases are restricted due to an already high wing loading (Guillemette 1994). A combination of shorter migratory distances and decreased need to build energy stores resulting from hyperphagia before spring migration may explain the shorter spring migratory duration of *dresseri* eiders. Furthermore, the longer duration and high variability in duration of fall migrations that we report is similar to those reported above for more northern populations and may be the result of climatic conditions and food availability at stopover sites (Gordo 2007). Seasonal weather conditions and food availability can drastically change on an annual basis and additional monitoring over multiple years is necessary in order to fully understand the factors driving the timing and duration of eider migratory movements.

Eiders migrating between southern New England and northern summer areas appeared to use several different routes, although Goudie et al. (2000) suggested that eider generally migrate along coasts and tend to avoid terrestrial and pelagic routes. Due to the duty cycles of migratory eider, we could not develop accurate spatially-explicit

models of specific routes used by eiders migrating to and from southern New England, although some movements are worth noting. Some eiders breeding in the St. Lawrence Estuary, Canada use an overland migration route to migrate to coastal Maine (Gauthier et al. 1976). We detected 1 eider approximately 60 km inland over Quebec that was detected 1 hr later on the eastern shore of the St. Lawrence Estuary. In addition, 4 eiders migrated overwater from Cape Cod, Massachusetts to Nova Scotia, Canada based on 4 to 5 sequential pelagic locations in the Gulf of Maine during single 4-hr duty cycles for each bird. One eider spent 2 days in northeast Nova Scotia before migrating to Prince Edward Island, Anticosti Island and eventually reached the north shore of the Gulf of St. Lawrence. During fall 2012 migration, two of these birds migrated from Nova Scotia, Canada to Maine, USA before returning to the southern New England wintering area. We also documented a single overwater migration from Cape Cod, Massachusetts, USA to Nova Scotia, Canada during spring 2013. To our knowledge, these are the first documented cases of eider migrating far offshore during spring migration between southern New England and Nova Scotia. The straight-line distance between southern Nova Scotia and Cape Cod is 380 km, whereas a northward flight along the New England coastline before crossing the Bay of Fundy is likely to exceed 600-700 km. Thus some female eiders apparently conserve energy and nutrient reserves by undertaking a more direct over-water flight.

### **Diurnal and Nocturnal Movements**

The short offshore movements at dusk that we documented in southern New England are similar to those recorded for northern common eiders in Southwest Greenland (Merkel et al. 2006). At Nantucket, Massachusetts, Mackay (1890) reported eiders flying offshore to

roost at night and returning to nearshore waters at dawn. Winiarski et al. (2011) recorded eiders flying offshore at dusk; however, they were unable to determine the location of offshore roosts. During capture efforts, we rarely encountered eiders at nearshore capture locations during pre-dawn hours; however at dawn, eiders started to fly inshore from apparently offshore roosts (J. Beuth, personal observation). Analysis of telemetry data showed a difference of 0.92 km between diurnal and nocturnal locations; however, this difference fell within the < 500m error radius of the diurnal and nocturnal telemetry locations, therefore the diel migration distances must be interpreted cautiously. Despite nocturnal locations being slightly further from shore and having increased water depth, with the exception of one eider (ptt 112416), the average water depth during the nocturnal period was within approximately 20 m; thus, the birds were apparently roosting in relatively shallow areas.

### **Winter Home Ranges**

Core use areas (50%) of eiders in this study averaged  $38.5 \pm 7.9 \text{ km}^2$  and utilization distributions (95%) averaged  $199.3 \pm 32.7 \text{ km}^2$ , which was considerably larger than average core use areas ( $8.1 \pm 1.3 \text{ km}^2$ ) and utilization distributions ( $67.8 \pm 8.3 \text{ km}^2$ ) reported by Merkel et al. (2006) for northern common eiders (*Somateria mollissima borealis*) wintering in southwest Greenland. However, Merkel et al. (2006) derived core use areas and utilization distributions of eiders from an average of 39 tracking days, which was far fewer than the 128 days we used (Table 2-2). Of the 32 eiders monitored by Merkel et al. (2006), 72% had only 1 winter core use area whereas the other 31 eiders averaged 2.1 areas. In contrast, during this study, 17 of 21 eiders had only 1 winter core use area and the other 4 eiders each had 2 separate core use areas. Six eiders that we

tracked had only 1 continuous utilization distribution and the overall average was 2. The geographic layout of the fjords and seasonal ice coverage at Merkel et al.'s (2006) study area at Nuuk, southwest Greenland, possibly constrained eider movements and habitat use compared to the open ocean environment and lack of ice coverage in southern New England.

Eiders in our study had significantly smaller core use areas and utilization distributions than most other subspecies of eider as well as other species of sea ducks. For example, Pacific common eiders wintering in 4 distinct polynyas had median core use areas of 102 to 1,142 km<sup>2</sup> and median utilization distributions between 1,247 and 2,938 km<sup>2</sup> (Petersen et al. 2012). Average size of 50% core use areas and 95% utilization distributions of black scoters captured in New Brunswick, Canada and wintering in southern New England was  $686 \pm 142$  km<sup>2</sup> and  $3,855 \pm 688$  km<sup>2</sup>, respectively, which were larger than the  $267 \pm 182$  km<sup>2</sup> core use areas and  $1,645 \pm 1,107$  km<sup>2</sup> utilization distributions calculated for black scoters tagged in southern New England (Loring 2012). King eiders wintering in the Bering Sea had average winter ranges of  $6,905 \pm 11,523$  km<sup>2</sup> (Oppel et al. 2008). Many factors may influence the size of core use areas and utilization distributions of sea ducks during winter such as the inclusion of juveniles in a study, tracking method, transmitter duty cycles and data quality, method of home-range estimation, and the duration of the study (Reed and Flint 2007, Oppel et al. 2008, Loring 2012). Eiders in southern New England were relatively sedentary and had smaller core use areas and utilization distributions compared to other sea ducks which may limit encounters with OWEDs provided the developments are not sited in areas of high use by eiders.

## Site Fidelity

Eiders during this study exhibited high intra- and inter-annual fidelity to southern New England. Philopatry of eider to specific breeding areas has been well documented (e.g., Reed 1975, Wakely and Mendall 1976); however, to our knowledge we present the first evidence supporting high fidelity of American common eiders (*Somateria mollissima dresseri*). In contrast, black scoters showed only moderate fidelity with less than half of the birds returning to southern New England (Loring 2012). Petersen et al. (2012) found that 18 of 19 Pacific eiders were site faithful and, of those that returned, 95% used the same home range as the previous winter. The high levels of fidelity we observed for eiders were greater than those reported for harlequin ducks (*Histrionicus histrionicus*) (62% females and 77% males) (Robertson et al. 2000). Roberston and Cooke (1999) suggest that “local-knowledge” of food resources and predator avoidance may drive high fidelity to wintering areas. Eiders are known to pair relatively early in the wintering period and breeding females have been observed with the same mate in consecutive years (Spurr and Milne 1976). High site fidelity of eiders to their wintering area facilitates early reestablishment of pair bonds and may minimize costs associated with pair-bonding and competition (Ashcroft 1976, Spurr and Milne 1976) during winter which already has high energetic demands due to shorter day lengths, less time foraging and lower temperatures.

High site fidelity of eiders to their wintering areas may also have costs including increased exposure to anthropogenic disturbances associated with OWED, hunting, climate change, and diseases. We estimated little spatial overlap between the proposed OWEDs in Rhode Island and habitat with a high probability of eider use. However, the cumulative impacts of disturbance associated with construction and maintenance of

multiple OWEDs could affect eiders in southern New England. Climate change may lead to an increase in the frequency and severity of coastal storms which could scour the nearshore habitats of southern New England and decrease benthic food supplies. Experiments in Italy showed that increased frequency and severity of climatic events negatively affects invertebrate abundance and diversity (Vaselli et al. 2008). For some waterfowl species, breeding success has been shown to increase in relation to above average foraging conditions during the preceding winter (Ankney and MacInnes 1978). High site fidelity could repeatedly subject eider to inadequate food availability and decreased profitability of foraging as a result of an increase in severe weather events associated with climate change which could lead to lower breeding success.

In addition, high site fidelity to areas with above average hunting pressure may subject eiders to increased mortality, displacement from preferred foraging areas, and increased flight times. Analysis of northern common eider harvest in Greenland found that harvest levels were unsustainable and models predicted significant population declines as a result (Gilliland et al. 2009). Presently it is difficult to measure the effects of hunting on American common eiders because harvest data is insufficient (Caithamer et al. 2000), thus caution should be used when setting seasons with liberal harvest limits. Furthermore, high site fidelity repeatedly exposes eiders to diseases such as Wellfleet Bay Virus (WBV) which has killed several hundred to several thousand eiders annually over the last several years on the wintering area in Cape Cod Bay, Massachusetts (Ellis et al. 2010). Exposure to disease on the wintering areas is less likely to impact entire breeding colonies because eiders from many breeding areas mix throughout the winter range (Goudie et al. 2000). However, the transmission of diseases such as Wellfleet Bay

Virus is not well understood and the potential exists for disease to severely impact large flocks that congregate on the wintering grounds. Obtaining a more thorough understanding of the effects of climate change, anthropogenic disturbances and disease on eiders during the winter period will enable managers to better predict the impact these variables will have individually or cumulatively on eider populations.

### **Habitat Use and Resource Selection**

Until now, knowledge of habitat use by eiders in southern New England has been limited to inferences made from aerial and ship-based surveys in addition to land based surveys during daylight hours (McKinney 2004, McKinney et al. 2006, Winiarski et al. 2011). Our research is the first to use satellite telemetry to document movements of eider during winter and then assess habitat characteristics in those areas most heavily used by eider. Habitat characteristics important for eider included sites that were closer to shore with shallower water depths, a higher probability of hard bottom, and relatively fine sandy substrates (Table 2-6). This corroborates findings by Winiarski et al. (2011) that eider are most abundant in areas with water depths of less than 25 m and areas classified as rocky headlands in the lower part of Narragansett Bay (McKinney et al. 2006). Benthic communities of lower Narragansett Bay are predominately mussel beds (Schwartz 2009) which provide preferred foraging opportunities for eiders, thus explaining the frequent detections and high abundance counts in previous studies and the high level of use observed in our study.

Overall, 3% and 10% of the study area was classified as high and medium high probability of use, respectively. The validation of the resource selection function model confirms that the areas classified as medium high and high probability of use are those



most likely to be used by eiders; these areas include rocky outcroppings and submerged reefs under relatively shallow water extending out from shoreline. The hard bottom provided by the rocky outcroppings and reefs provide ideal attachment locations for benthic invertebrates, such as mussels on which eiders forage.

## **MANAGEMENT IMPLICATIONS**

The portion of the study area where the Rhode Island-Massachusetts Area of Mutual Interest (AMI) is located was classified as low probability of use for eiders. The AMI area is far from shore, relatively deep, had fine sediments and low probability of hard bottom, which suggests this area would not be regularly used by foraging or roosting eiders. However, eiders may fly through the AMI area during spring or fall migration or while moving locally throughout the winter, although we have no indication from satellite-tagged birds that this would happen often. Research in Europe found that collision risk with offshore wind turbines is minimal for sea ducks, although deflection may lead to increased flight times (Desholm and Kahlert 2005). Masden (2009) suggested that the increased flight distance and times resulting from deflection at one offshore wind farm were trivial and unlikely to have significant impacts; however, more study is needed on the potential effects of multiple OWEDs within an eider's utilization distribution.

Although we did not capture any eider for this study off of Block Island, some birds we tagged did use nearshore waters near Block Island. Construction of wind turbines within the Block Island Renewable Energy Zone (BI-REZ) are more likely to impact eiders wintering in southern New England than those within the AMI. The total footprint of the BI-REZ is approximately 34 km<sup>2</sup>, of which 0.81 km<sup>2</sup> (2.4%), 20.8 km<sup>2</sup>

(61.3%) and 12.3 km<sup>2</sup> (36.3%) was classified as medium-high, medium and medium-low probability of use, respectively. Based on research conducted at European offshore wind farms, we suspect that the construction of offshore wind turbines in this region could displace some eiders from foraging habitat (Larsen and Guillemette 2007) and could increase flight times between foraging and roosting sites (Desholm and Kahlert 2005, Masden et al. 2009). However, displacement may be relatively short-term given that sea ducks, such as black scoters in Europe, may habituate to wind turbine structures and eventually reoccupy the development's footprint (Petersen and Fox 2007). We know of no similar studies that document habituation of eiders to offshore wind turbines even though eiders are common in areas with OWED in Europe. The habitat that may be lost due to displacement by the BI-REZ is 5.3% of the 1873.4 km<sup>2</sup> of habitat classified as medium-high to medium-low probability of use. Monitoring of eider movement ecology during and after construction of offshore wind turbines within the BI-REZ would allow these effects on sea ducks wintering in southern New England to be quantified and so inform future decisions about siting of OWED in the region.

Boat traffic associated with the construction and maintenance of the several proposed OWEDs in the region may have the most profound effects on wintering sea ducks. Schwemmer et al. (2011) found that disturbances caused by ship traffic lead to decreased foraging, temporary loss of habitat, and increased flight times and presumably energetic costs for sea ducks. Of the 5 species of sea ducks studied by Schwemmer et al. (2011), eider showed the highest tolerance of shipping traffic with median flush distances from ships of 208 m compared to 804 m for common scoters (*Melanitta nigra*), 404 m for white-winged scoters (*Melanitta fusca*) and 293 m for long-tailed ducks (*Clangula*

*hyemalis*). The port at Quonset Point, Rhode Island, has been identified as a likely staging area for wind turbine construction and maintenance work. Boats traversing between Quonset Point and OWEDs would pass through areas of southern Narragansett Bay classified as high and medium-high likelihood of use by eiders. Although quantifying increased flight times and energetic costs associated with flushing caused by boat traffic linked to offshore developments may be difficult, future research should aim to measure these effects on eiders. Information obtained may enable managers to recommend staging locations for work associated with OWED that would minimize boat traffic through areas of high use and thus minimize disturbance of eiders during the winter period.

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Table 2-1. Performance of 24 satellite transmitters (PTT) deployed on adult female common eiders during November and December 2011 in Rhode Island, USA. Total number of locations for each bird (total loc.) is the sum of the single best locations per duty cycle from the date of deployment (deploy) until the last location received (last loc.).

PTT	Date			Percent of locations per class <sup>a</sup>						
	Deploy	Last loc.	Total loc.	LC 3	LC 2	LC 1	LC 0	LC A	LC B	LC Z
112413	11/15/11	12/15/12	169	88.8	9.5	0.6	0.0	0.6	0.6	0.0
112414	11/14/11	7/16/13	208	73.1	19.7	3.8	0.0	2.9	0.5	0.0
112415	11/17/11	7/14/13	201	55.2	23.9	6.0	3.0	8.5	3.5	0.0
112416	11/17/11	6/17/13	208	81.3	16.3	1.4	0.5	0.0	0.5	0.0
112417	11/14/11	1/16/13	174	75.3	22.4	2.3	0.0	0.0	0.0	0.0
112418 <sup>b</sup>	11/17/11	7/15/13	178	48.3	15.7	7.9	2.2	12.4	13.5	0.0
112419	11/18/11	5/27/13	204	86.8	10.3	2.5	0.5	0.0	0.0	0.0
112420 <sup>b</sup>	11/18/11	3/26/13	190	82.6	16.3	0.5	0.5	0.0	0.0	0.0
112421	11/21/11	4/4/13	191	73.3	18.3	3.7	1.0	2.6	1.0	0.0
112422	12/6/11	12/13/12	163	89.6	5.5	1.8	0.0	1.2	1.8	0.0
112423	11/21/11	7/13/13	203	70.4	19.2	2.0	3.0	3.0	2.5	0.0
112424	11/21/11	6/6/13	202	79.7	9.4	2.5	1.5	5.9	0.5	0.5
112426	12/6/11	7/13/13	208	88.0	9.1	1.4	0.5	1.0	0.0	0.0
112428	12/6/11	7/13/13	205	66.8	21.5	2.9	2.4	3.9	2.4	0.0
112429	12/6/11	7/14/13	203	79.3	15.3	1.5	0.5	1.5	2.0	0.0
112430	12/6/11	7/16/13	210	85.2	13.3	1.4	0.0	0.0	0.0	0.0
112431	12/6/11	7/13/13	205	89.8	7.8	1.5	0.0	0.5	0.5	0.0
112432 <sup>b</sup>	12/6/11	7/16/13	208	77.4	15.9	1.4	1.0	2.4	1.9	0.0
112433	12/6/11	11/15/12	157	36.3	33.1	19.7	4.5	3.8	1.9	0.6
112434	12/6/11	7/14/13	206	50.5	33.5	11.2	1.5	2.4	1.0	0.0
112435	12/10/11	7/13/13	205	58.0	26.8	8.8	3.9	1.5	1.0	0.0
112436	12/10/11	7/16/13	205	62.4	24.4	10.7	0.5	1.0	1.0	0.0
112437	12/11/11	7/14/13	203	51.2	29.1	12.3	1.0	4.4	2.0	0.0
112438	12/11/11	7/14/13	204	53.4	26.5	14.7	1.5	3.4	0.5	0.0
Average	11/28/11	5/26/13	196	70.9	18.5	5.1	1.2	2.6	1.6	0.0
Std.	2.1	16.5	3.2	3.17	1.61	1.06	0.27	0.60	0.55	0.03

<sup>a</sup> Location class is defined by accuracy intervals (m): LC 3 (<250), LC 2 (250-<500), LC 1 (500-<1,500) and LC 0 (>1,500), whereas location accuracy is not assigned for LC A, LC B, and LC Z.

<sup>b</sup> Birds that left the study area before the end of winter 2011-12.

Table 2-2. Length of stay during winter and summer, and duration of the migratory period (mean no. days, range) for 24 adult female common eiders implanted with satellite transmitters during November and December 2011 in Rhode Island, USA. Fewer eiders were transmitting over time because transmitters failed almost immediately (2), birds departed from the study area during the first winter (3), birds were shot during the hunting season (2), and eventually the transmitters stopped transmitting after 1.5 yrs (5). The delineation of each seasonal period is described in the text.

Seasonal period	<i>n</i>	Duration (days)	Range (days)
Winter 2011-12	21	128	103-152
Spring 2012 Migration	21	16	2-47
Summer 2012	21	168	93-253
Fall 2012 Migration	19	47	7-115
Winter 2012-13	14	141	55-223
Spring 2013 Migration	14	20	1-61

Table 2-3. Average distances to shore (km) and water depths (m) for high quality diurnal and nocturnal locations (LC 3 and LC 2) of 21 adult female common eiders that remained on the southern New England study area (Figure 2-1) for the entirety of winter 2011-12.

Transmitter ID	Distance to Shore (km)		Water Depth (m)	
	Diurnal	Nocturnal	Diurnal	Nocturnal
112413	0.28	1.59	6.4	18.7
112414	0.65	1.88	11.9	20.6
112415	1.85	2.36	8.7	11.1
112416	1.36	2.23	15.7	22.5
112417	0.51	1.06	11.3	14.3
112419	1.75	2.98	11.5	16.3
112421	1.71	2.41	8.0	10.6
112422	0.26	0.46	4.4	8.4
112423	0.95	1.10	6.9	8.1
112424	1.46	2.17	10.9	19.2
112426	0.46	1.47	9.1	17.7
112428	0.38	1.44	11.9	19.5
112429	0.50	2.17	15.7	21.3
112430	1.59	3.05	6.8	12.5
112431	0.61	0.57	16.8	13.4
112433	0.31	1.68	1.8	19.8
112434	0.68	2.02	14.2	20.5
112435	0.62	2.03	4.0	16.0
112436	0.74	1.07	14.2	10.1
112437	0.51	1.84	7.1	16.5
112438	0.69	1.56	0.2	13.9
Average	0.85	1.77	9.4	15.8
Standard Error	0.12	0.15	1.01	0.96

Table 2-4. Total area (km<sup>2</sup>) of core-use (50% core) and utilization distributions (95% UD), and number of UD's per bird for 21 adult female common eiders (Trans #) that spent the entire winter 2011-12 period within the study area and for 3 adult female eiders that spent most of the winter period outside the study area.

Winter region	Trans. (#)	50% Core (km <sup>2</sup> )	95% UD (km <sup>2</sup> )	UD areas (#)
Within study area	112413	13.6	102.7	2
	112414	46.0	252.7	2
	112415	10.9	95.1	2
	112416	121.4 <sup>a</sup>	516.6	2
	112417	11.7	43.3	1
	112419	126.8 <sup>a</sup>	602.3	1
	112421	12.7	102.6	3
	112422	12.8	72.7	3
	112423	13.1	89.7	3
	112424	15.7	116.4	1
	112426	36.6	216.3	2
	112428	17.3 <sup>a</sup>	103.9	1
	112429	41.3	228.2	2
	112430	14.4	89.8	1
	112431	11.4	66.6	3
	112433	99.5 <sup>a</sup>	359.0	2
	112434	62.2	285.2	2
	112435	51.6	281.1	2
	112436	15.8	93.6	1
	112437	52.2	262.9	2
	112438	20.8	204.3	4
	<b>Average</b>	<b>38.5</b>	<b>199.3</b>	<b>2</b>
Outside study area	112418	310.7	2412.5	2
	112420	304.9 <sup>a</sup>	1896.5	2
	112432	270.1	1268.3	2
		<b>Average</b>	<b>295.2</b>	<b>1859.1</b>

<sup>a</sup> Eiders with two core-use areas. All other eider had only one core-use area.

Table 2-5. Mean ( $\bar{x}$ )  $\pm$  standard error (SE) and values for each habitat variable sampled within 95% utilization distributions (available) and 50% core use areas (used) of adult female common eiders in southern New England during winter 2011-12. Sample size ( $n$ ) is the number of resource units sampled within the composite available and used areas.

Habitat variable	Available		Used	
	$\bar{x} \pm \text{SE}$	$n$	$\bar{x} \pm \text{SE}$	$n$
Distance to shore (km)	2.94 $\pm$ 0.044	3,014	1.57 $\pm$ 0.055	580
Water depth (m)	20.38 $\pm$ 0.25	3,014	15.45 $\pm$ 0.43	580
Grain size (phi scale)	1.34 $\pm$ 0.019	2,839	1.76 $\pm$ 0.054	580
Hard bottom probability (0-1)	0.20 $\pm$ 0.003	3,014	0.30 $\pm$ 0.006	580
Slope (degree)	0.53 $\pm$ 0.012	3,014	0.70 $\pm$ 0.030	580
Roughness <sup>1</sup>	0.33 $\pm$ 0.006	3,014	0.42 $\pm$ 0.014	580

<sup>1</sup> Roughness of a resource unit is the standard deviation of the slope within a 1,000 m radius.

Table 2-6. Model parameters, Akaike Information Criterion (AIC), difference in AIC ( $\Delta$ AIC), relative likelihood and Akaike weights ( $w_i$ ) for 17 a priori logistic regression models used to estimate beta coefficients for an exponential resource selection function for common eider habitat use during winter 2011-12. Habitat characteristics used as model parameters include water depth (WD), distance to shore (DS), grain size (GS), relative probability of hard bottom (HBP), roughness (RG) and slope (SL).

Model parameters	AIC	$\Delta$ AIC	Relative likelihood	$w_i$
WD, DS, GS, HBP	2675.67	0.00	1.00	0.40
WD, DS, GS, HBP, RG	2677.15	1.48	0.48	0.19
WD, DS, GS, HBP, SL	2677.47	1.80	0.41	0.16
DS, GS, HBP	2677.88	2.20	0.33	0.13
WD, DS, GS, HBP, SL, RG	2678.36	2.69	0.26	0.11
WD, DS, GS, SL, RG	2769.09	93.42	0.00	0.00
WD, DS, GS	2771.91	96.24	0.00	0.00
WD, DS, GS, SL	2773.69	98.02	0.00	0.00
WD, GS, HBP	2817.44	141.77	0.00	0.00
WD, DS, HBP	2867.58	191.91	0.00	0.00
DS, HBP	2878.76	203.09	0.00	0.00
WD, DS	2978.03	302.36	0.00	0.00
DS	2982.68	307.01	0.00	0.00
WD, HBP	3001.44	325.77	0.00	0.00
HBP	3034.55	358.88	0.00	0.00
GS	3046.65	370.98	0.00	0.00
WD	3111.57	435.90	0.00	0.00

Table 2-7. Habitat characteristics and coefficients ( $\beta$ ) of the top ranked resource selection function derived for common eiders during winter on the nearshore and offshore waters of southern New England during winter 2011-12.

Habitat characteristic	$\beta$	Standard error
Intercept	-2.3073	0.143
Water depth (m)	-0.0112	0.0054
Distance to shore (m)	-0.4437	0.0403
Grain size (phi scale)	0.4883	0.0464
Hard bottom probability	2.8395	0.2885



Figure 2-1. Northeast region (inset) and southern New England study area where 26 adult female common eiders were captured and implanted with satellite transmitters during November and December 2011 in Rhode Island, USA. Inset shows areas where eiders were located during summer including: Maine (ME), Nova Scotia (NS), St. Lawrence Estuary (SLE) and Gulf of St. Lawrence (GSL).

Figure 2-2. Movement phenology of 21 adult female common eiders implanted with satellite transmitters in Rhode Island, USA during November and December 2011, their latitudes during summer in (A) St. Lawrence Estuary ( $n = 4$  birds), Maine ( $n = 9$  birds), (B) Gulf of St. Lawrence ( $n = 4$  birds) and Nova Scotia ( $n = 4$  birds), and their subsequent latitudes until the study ended in July 2013.

Figure 2-3. Winter 2011-12 composite core use area (50% core) and 95% utilization distribution (95% UD) of 21 adult female common eiders implanted with satellite transmitters during November and December 2011 in Rhode Island, USA that spent the entire winter in the study area. Centroids represent the center of each of 21 individual core areas.

Figure 2-4. Winter 2011-12 core use areas (50% core) and 95% utilization distributions (95% UD) of 3 adult female common eiders implanted with satellite transmitters during November and December 2011 in Rhode Island, USA that spent  $59 \pm 17\%$  of the winter outside of the study area.

Figure 2-5. Relative probability of use of nearshore and offshore waters by common eiders during winter 2011-12 in relation to the Block Island Renewable Energy Zone (BI REZ) and the Rhode Island/Massachusetts Area of Mutual Interest (RI-MA AMI).

Relative probability was derived from top-ranked logistic regression model (Table 2-6) and mapped using a resource selection function of the  $\beta$  coefficients from the top ranked model (Table 2-7).

Figure 2-6. Chi-Squared Goodness of Fit test results and linear regression analysis of expected and observed proportions of common eider locations within each probability of use class determined using Geometric Interval classification of the resource selection function values.

Figure 2-7. Site fidelity of eiders to the southern New England wintering areas. Locations of 19 adult female eiders during winter 2012-13 that were implanted with satellite transmitters in November and December 2011 are overlaid onto the composite utilization distribution and core use area derived from locations of 21 eiders during winter 2011-12.

Figure 2-1.

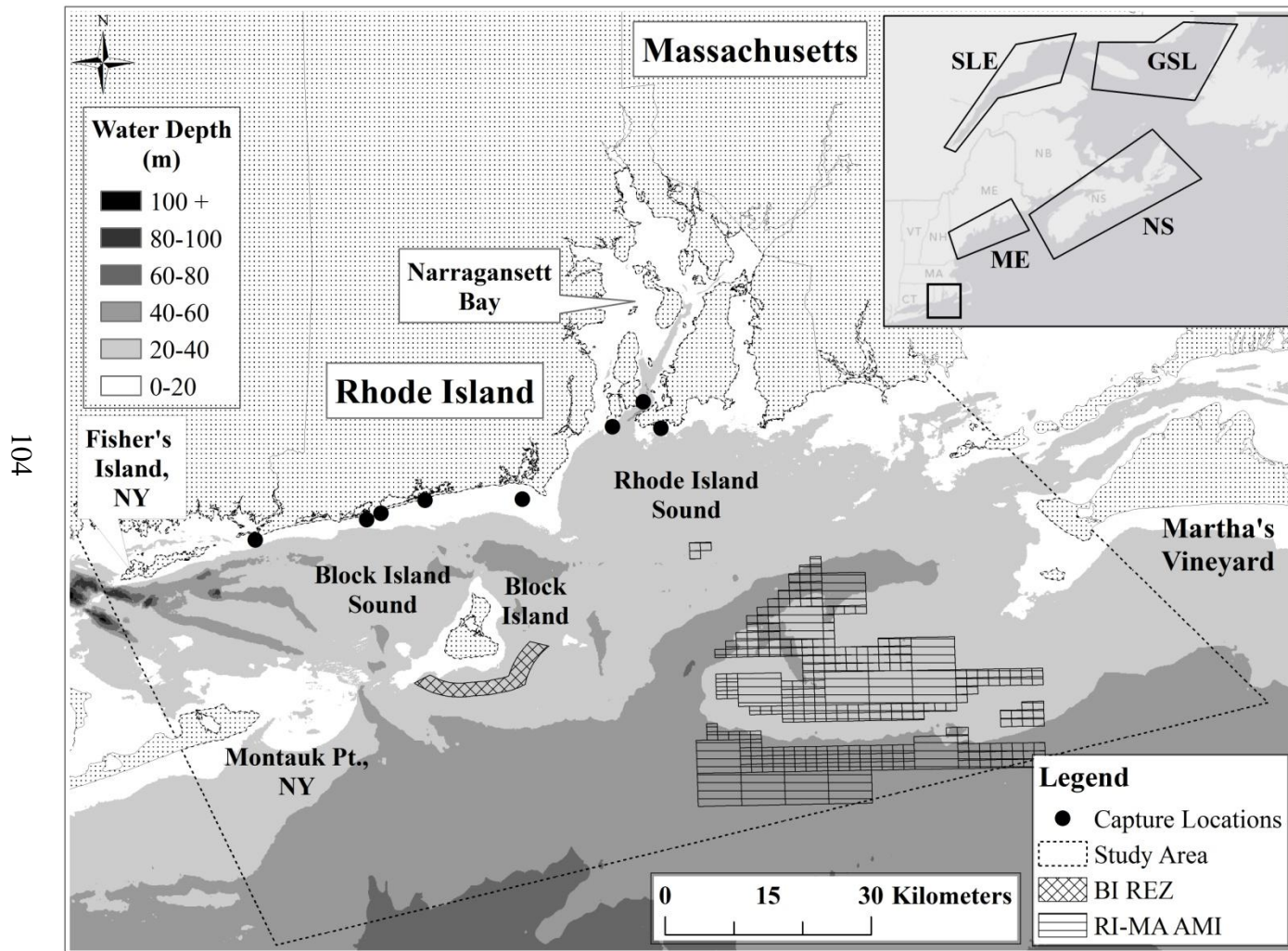


Figure 2-2 A.

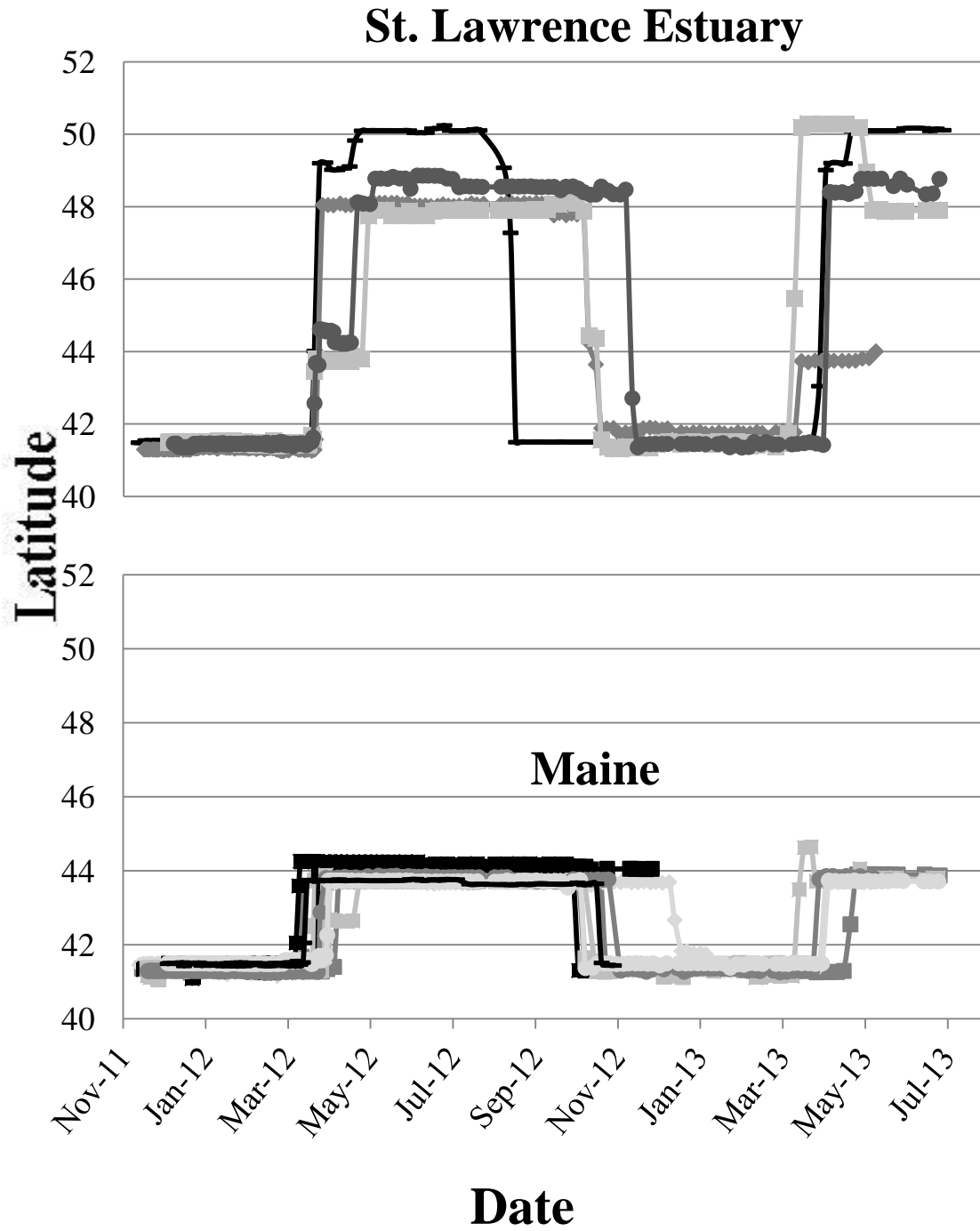
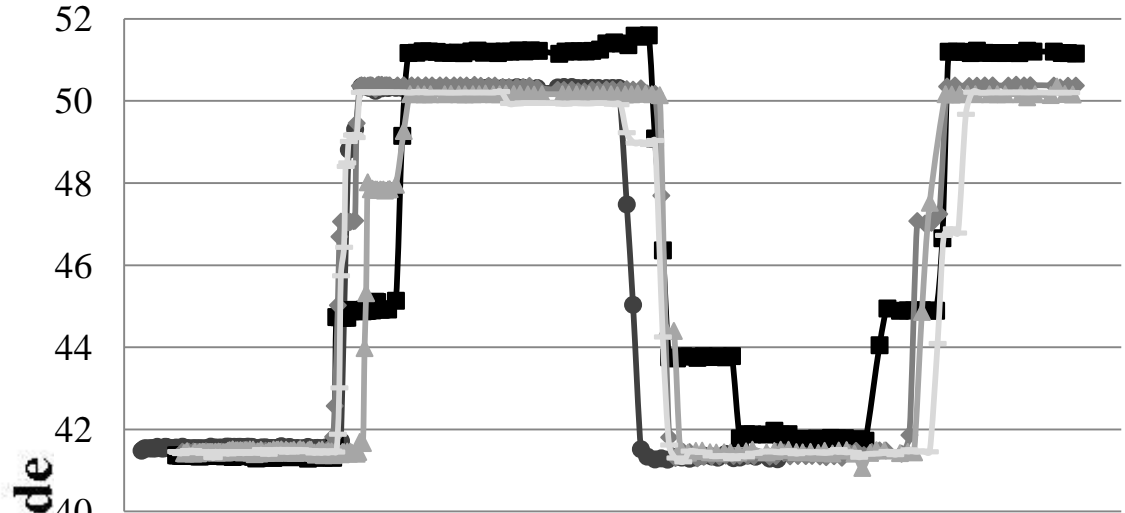


Figure 2-2 B.

## Gulf of St. Lawrence



## Nova Scotia

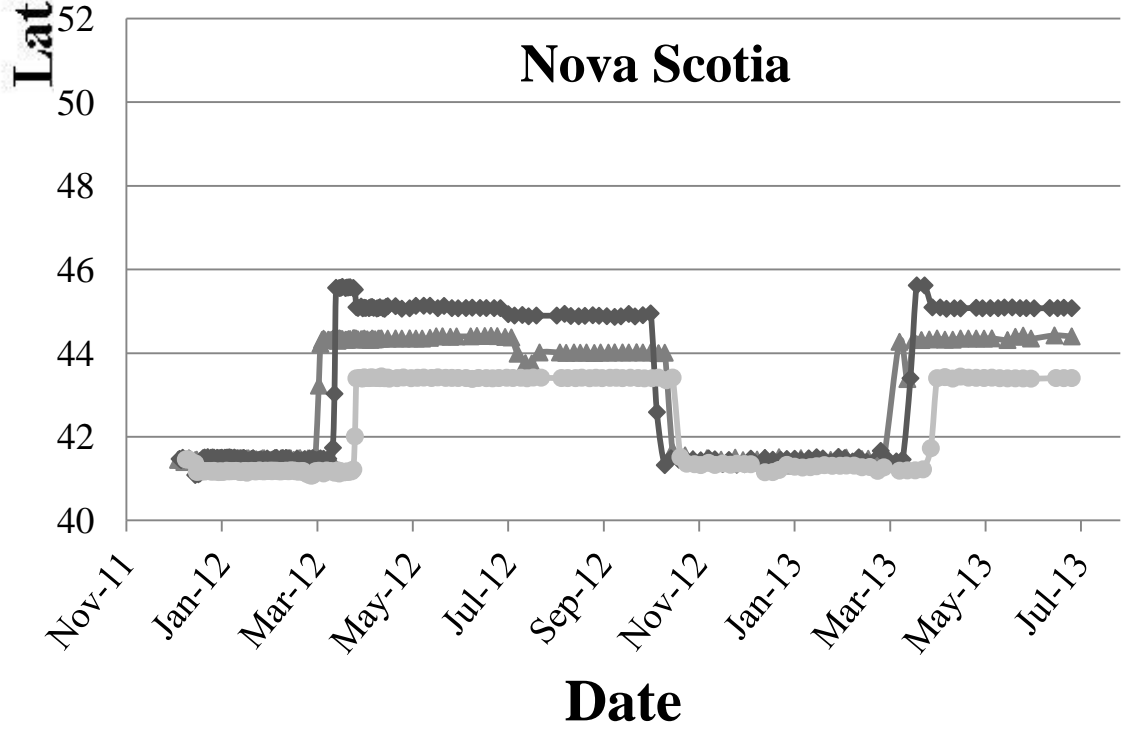
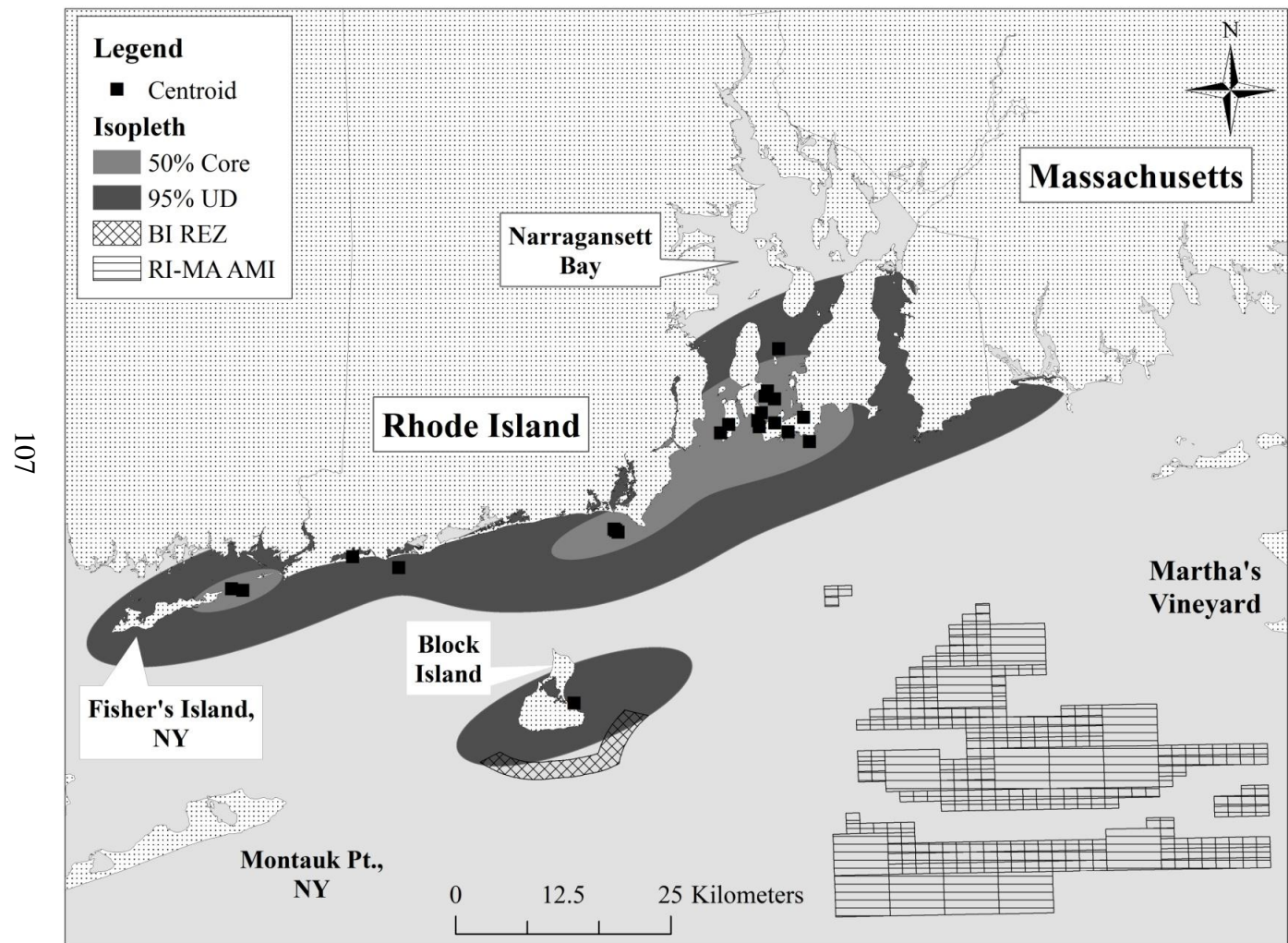


Figure 2-3.



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Figure 2-4.

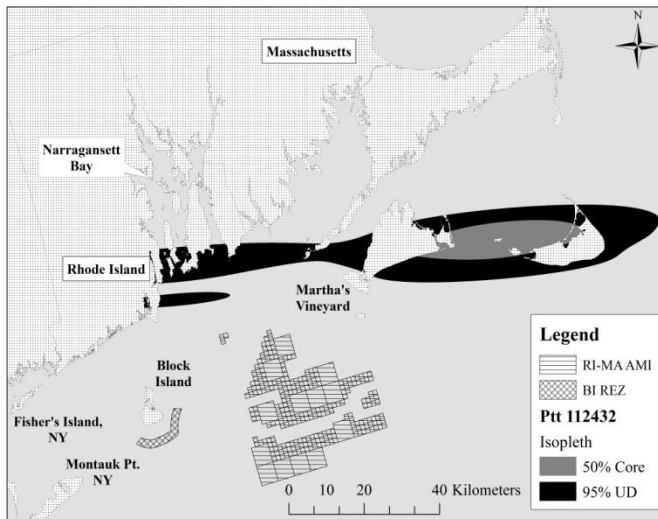
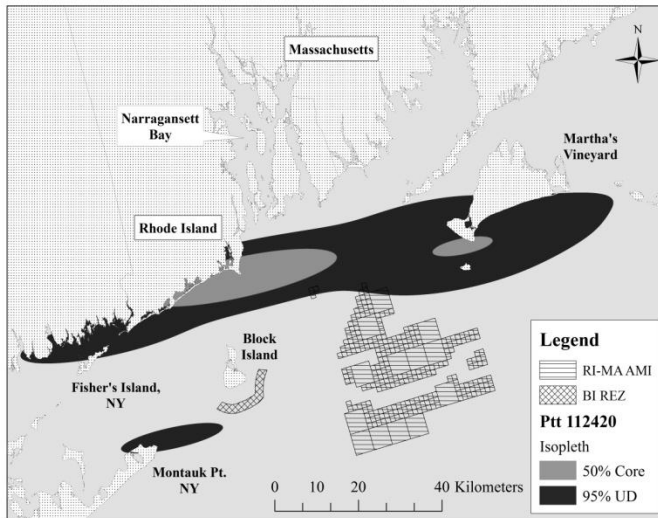
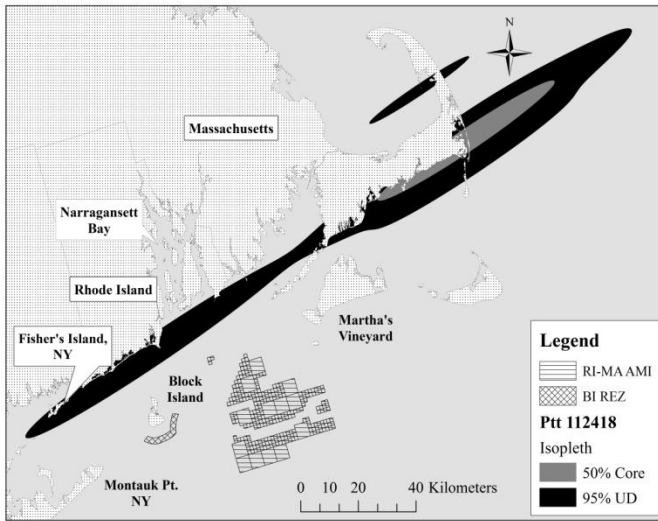




Figure 2-5.

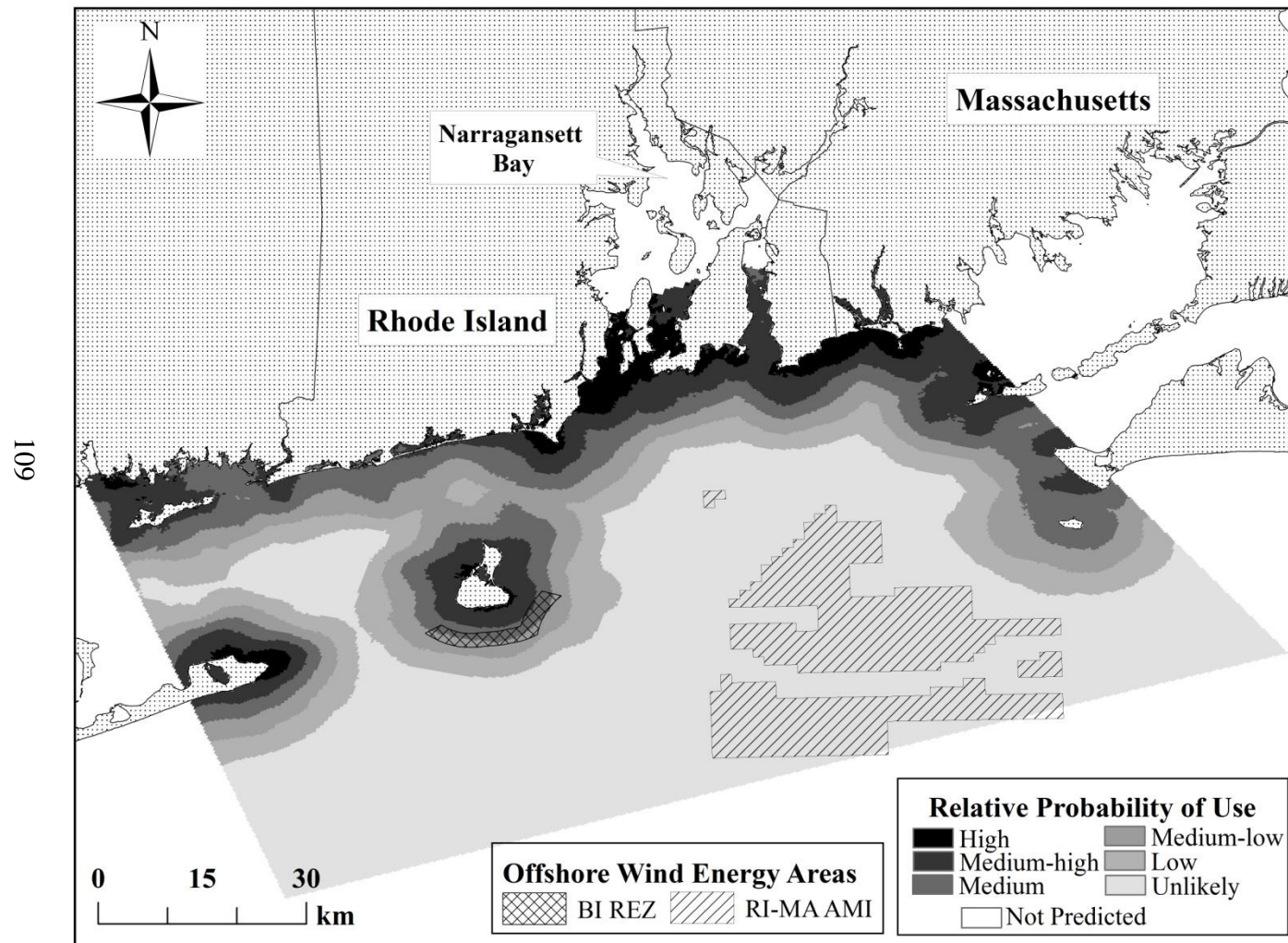




Figure 2-6.

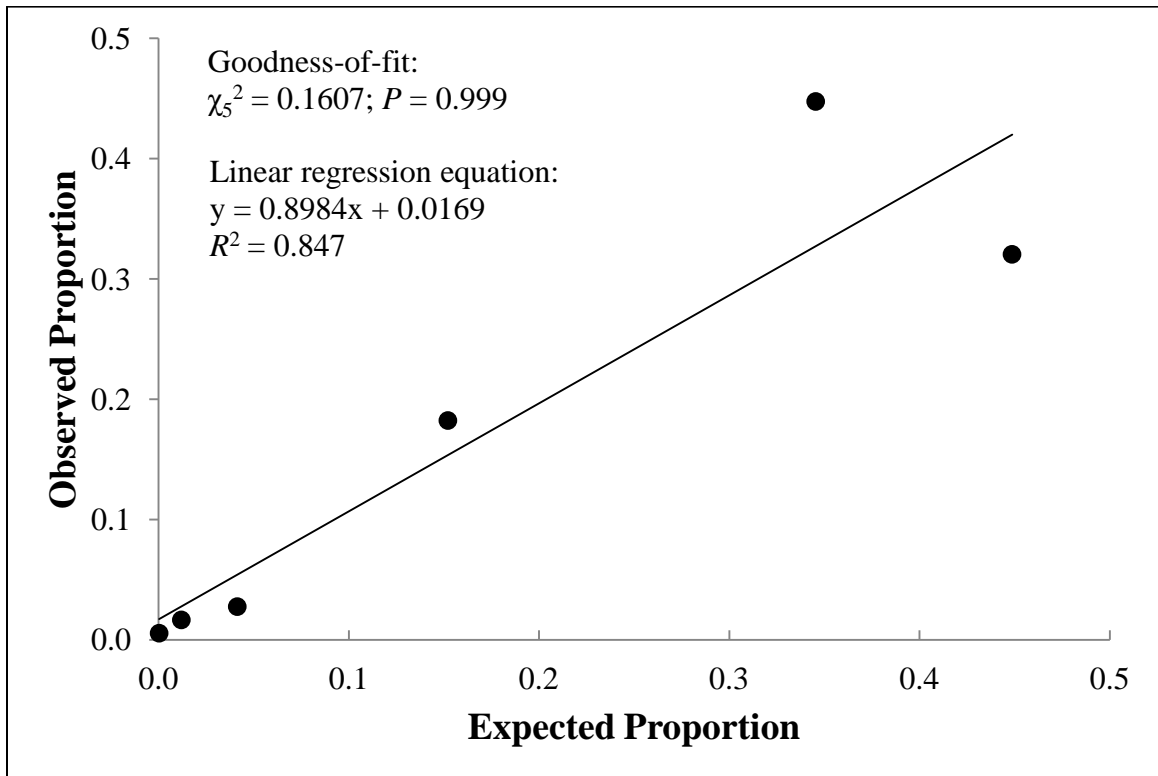
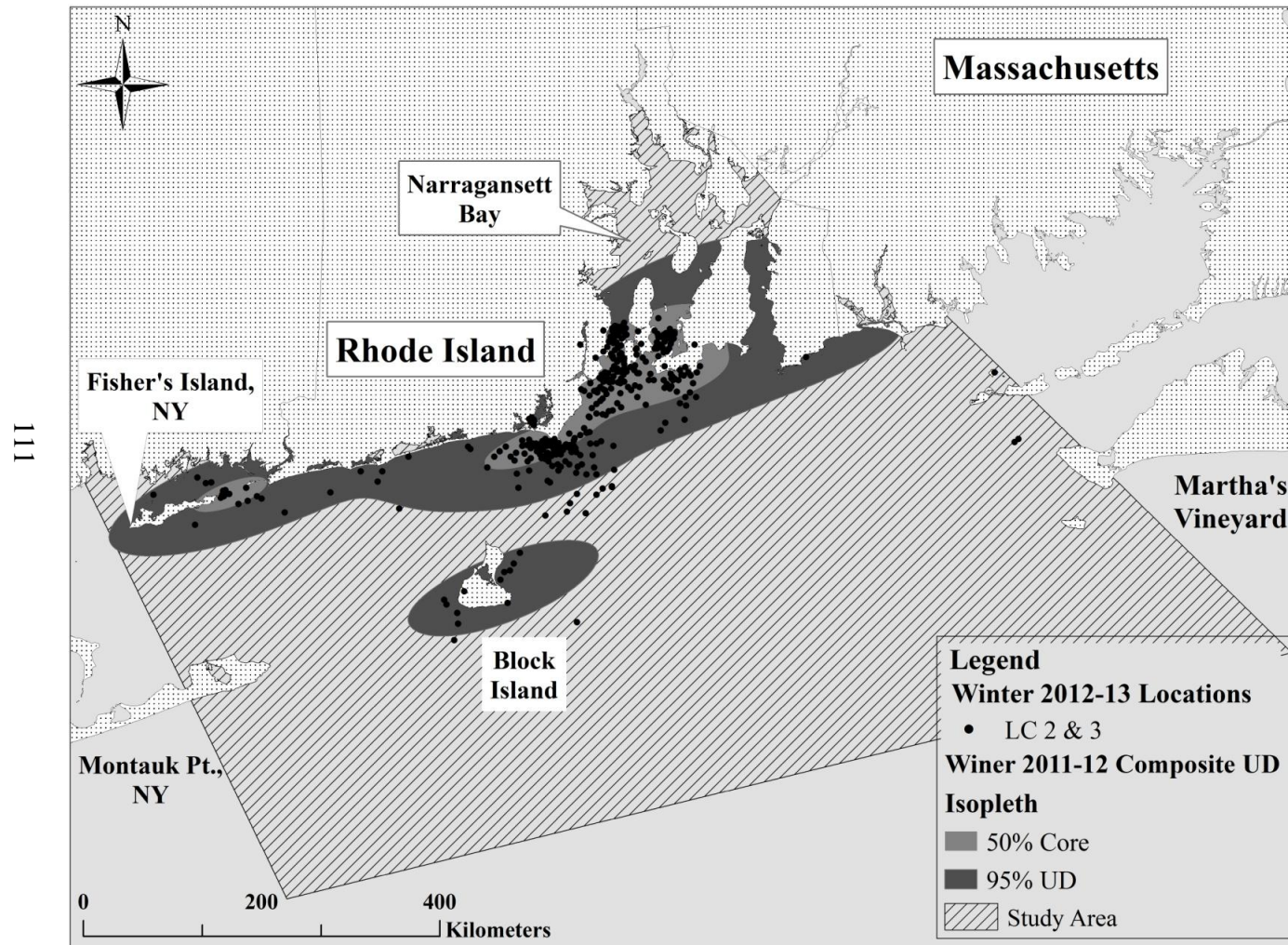


Figure 2-7.



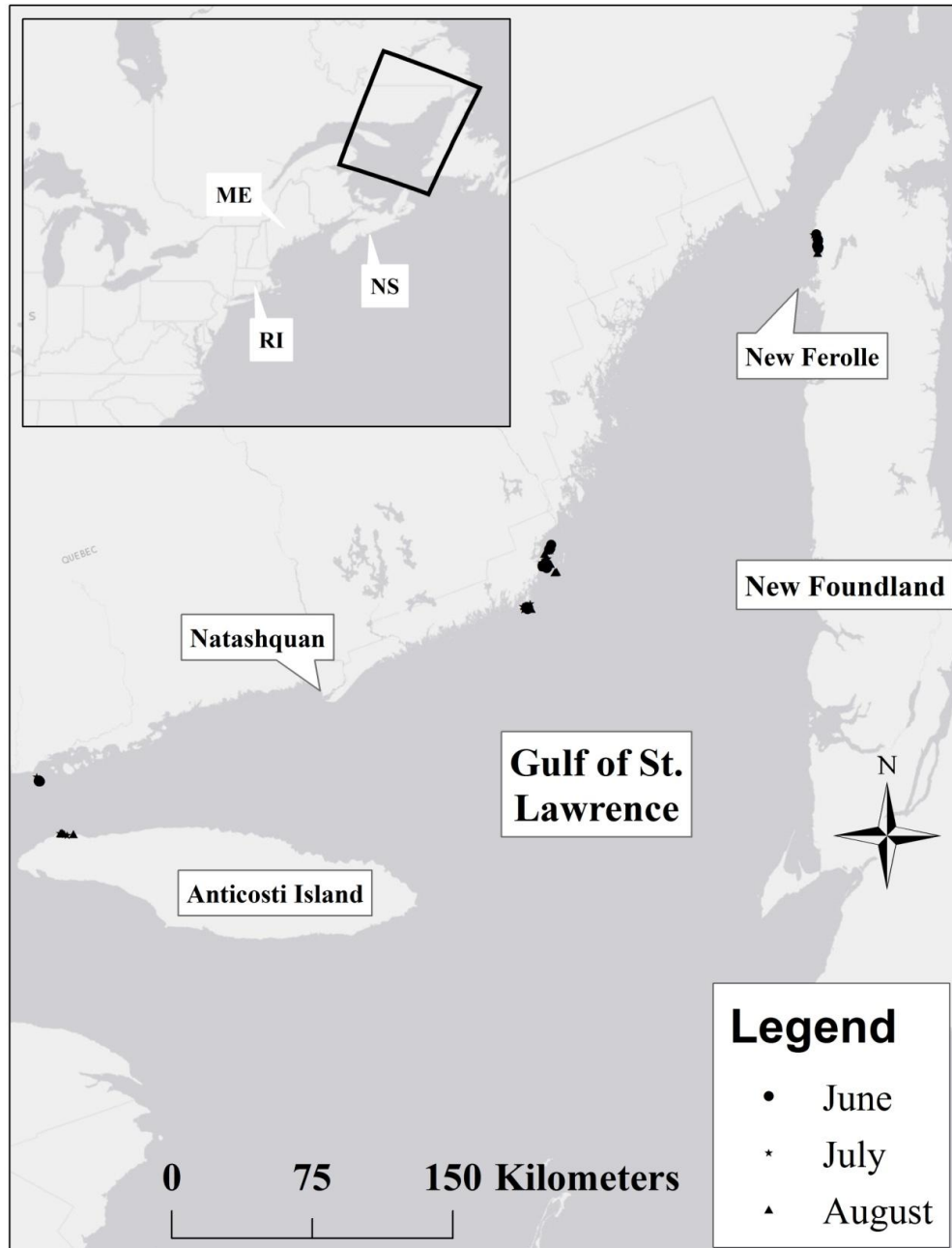
## **APPENDIX**

Figure A-2-1. Locations of adult female eiders in the Gulf of St. Lawrence, Canada (A;  $n = 4$ ), Maine, USA (B;  $n = 9$ ), Nova Scotia (C;  $n = 4$ ) and the St. Lawrence Estuary, Canada (D;  $n = 4$ ) during June, July and August, 2012. These 21 eiders were implanted with satellite transmitters on the southern New England study area during November and December 2011.

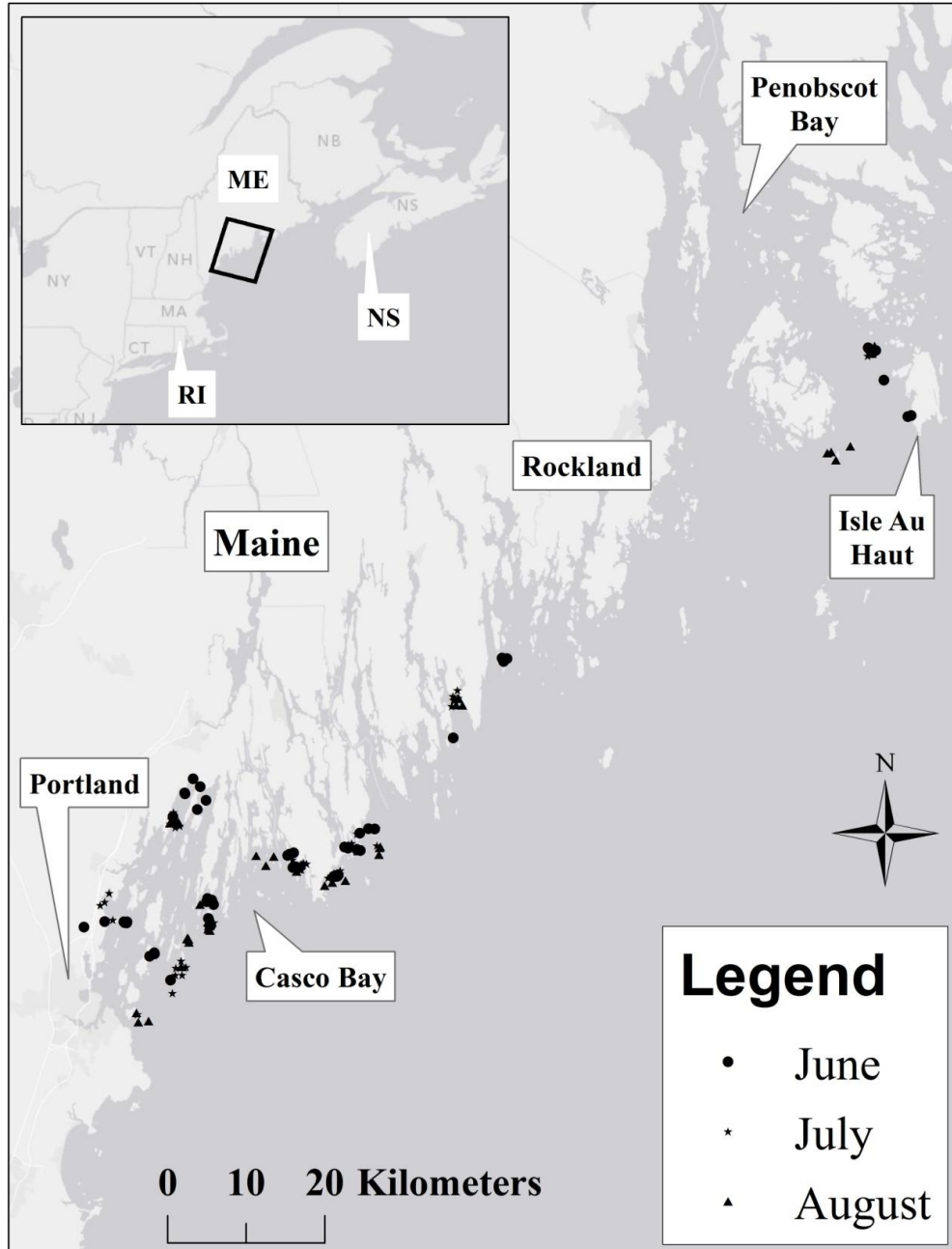
Figure A-2-2. Composite core use area (50% core) of 21 adult female common eiders implanted with satellite transmitters during November and December 2011 in Rhode Island, URA overlaid onto individual core use areas of the same 21 eiders (A) and Composite utilization distribution (95% UD) of the same 21 adult female common eiders implanted with satellite transmitters during November and December 2011 in Rhode Island, URA overlaid onto individual utilization distributions of the same 21 eiders (B).

Figure A-2-1.

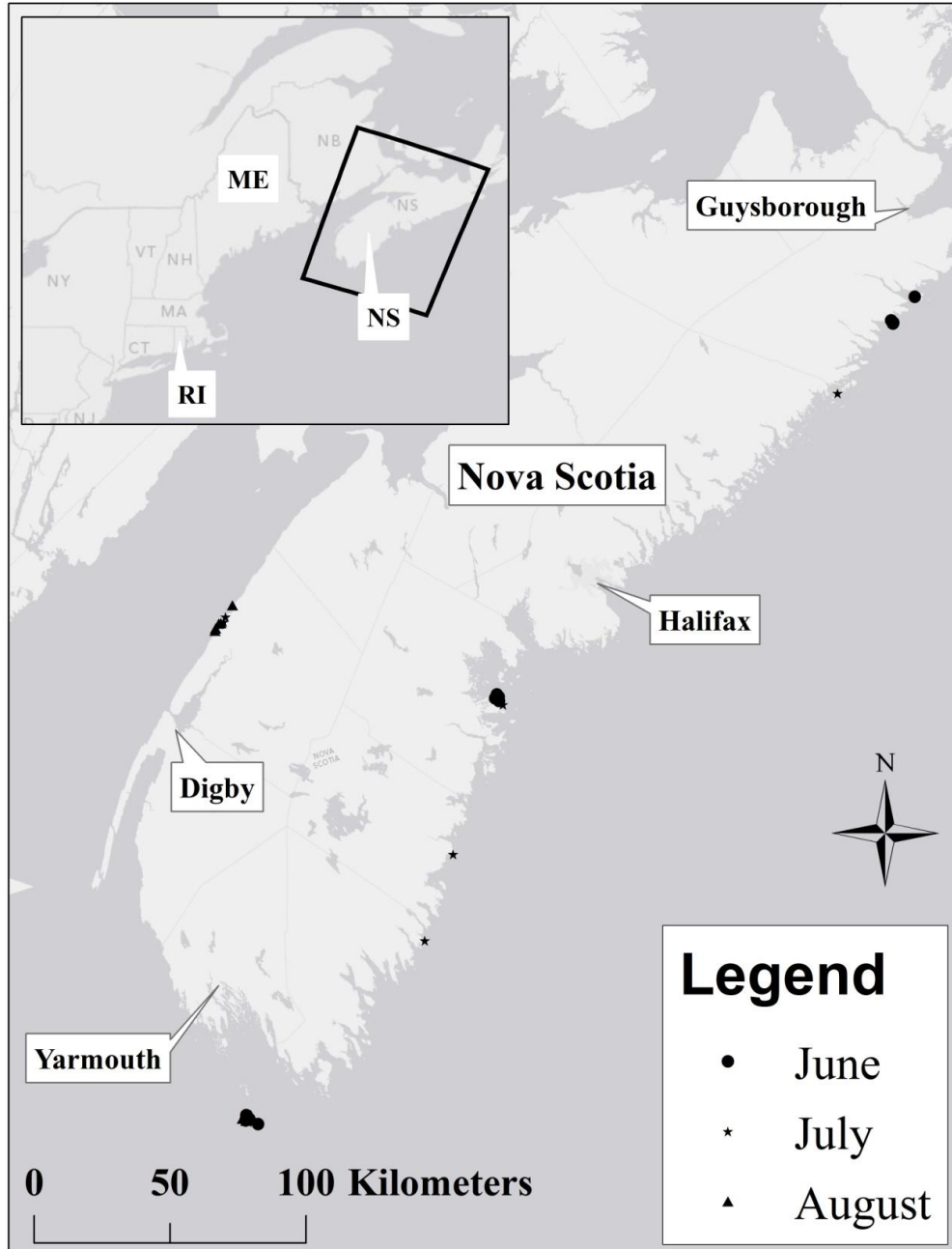
A.



B.



C.



D.

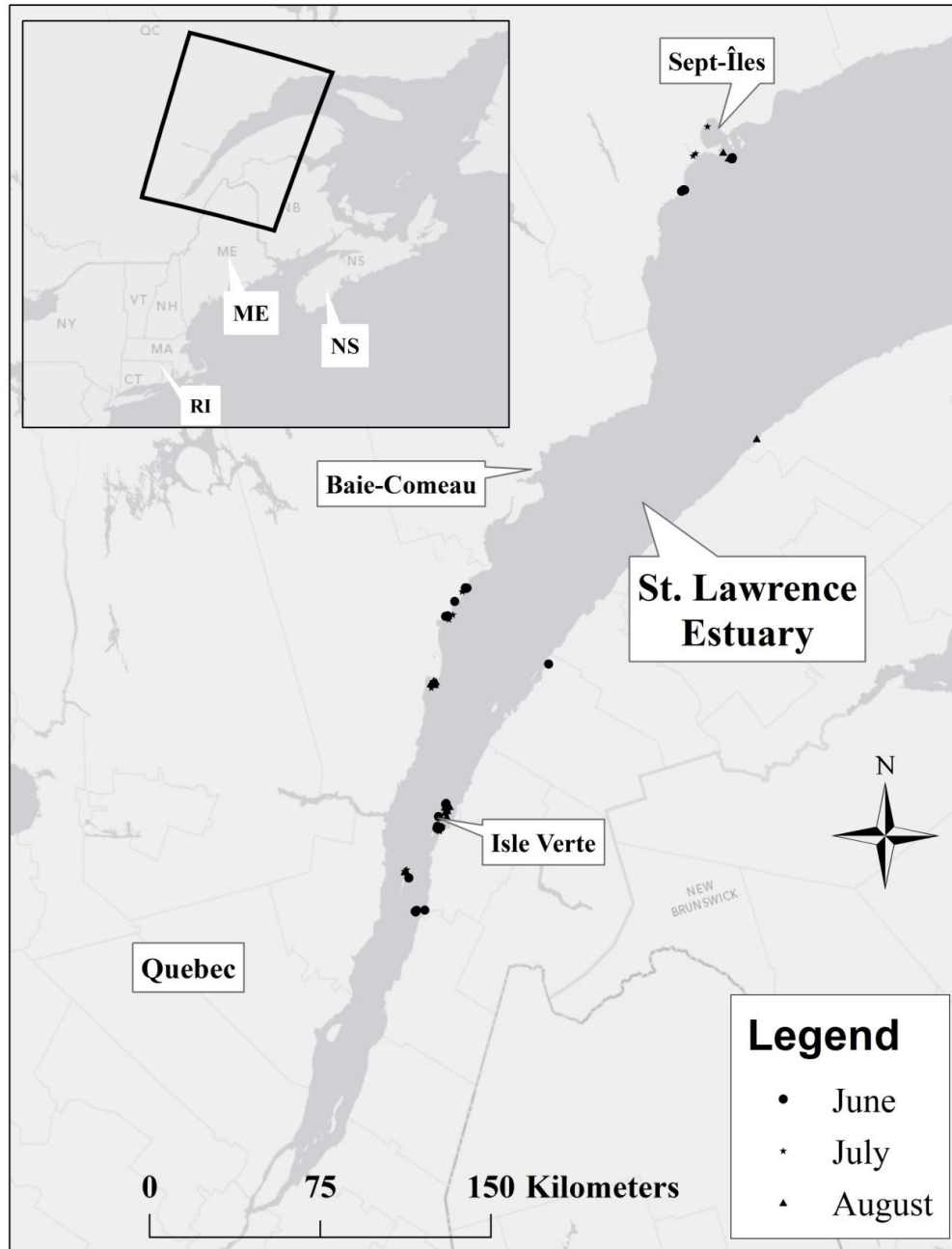
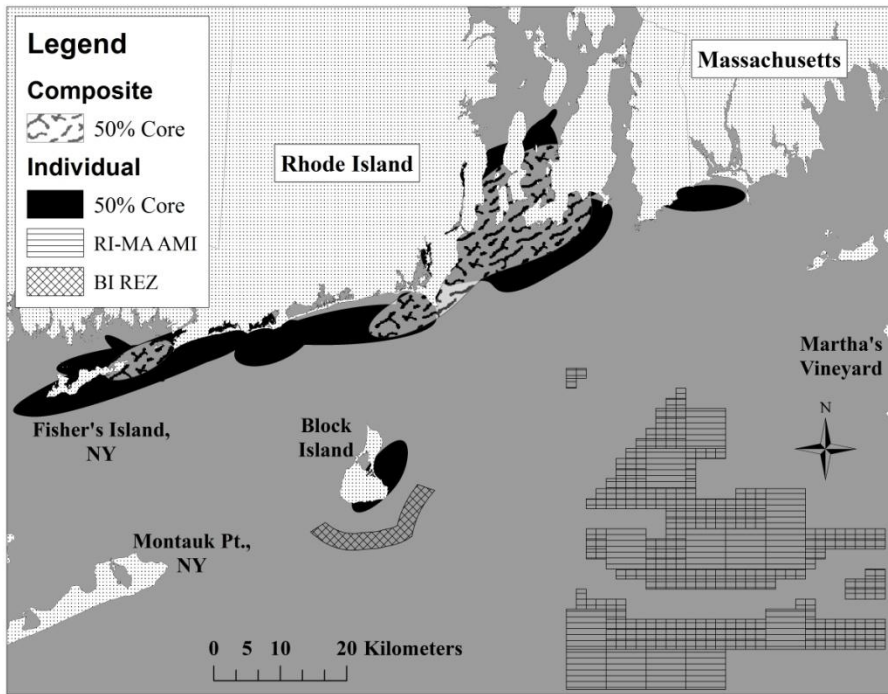




Figure A-2-2.

A.



B.

