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Using Land-based Surveys to Assess Sea Duck Abundance and Behavior in Nearshore Waters of Southern New England, USA

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Abstract.—Nearshore waters provide very important habitat for sea ducks (Tribe Mergini) during migration and winter, but gathering information on sea duck use of shallow nearshore waters is challenging because traditional aerial and boat-based surveys are expensive, are usually conducted infrequently, and are often not feasible near the coast. The objective of this study was to use land-based surveys to characterize spatiotemporal variation in the abundance and behavior (e.g., foraging, flying) of Common Eider (*Somateria mollissima*) and scoters (*Melanitta* spp.) in nearshore waters of southern New England. Surveys (60-120 min per survey, $n = 1,044$ surveys) were conducted throughout the day from February 2009 to July 2010 to assess diurnal and seasonal variation in sea duck behavior and spatial distribution at nine sites in southern Rhode Island. The density of sea ducks resting or foraging on the water exhibited little diurnal variation, whereas flight activity dramatically increased nearer to sunrise. Sea duck densities and passage rates (individuals/km^2/hr) peaked during migration periods from October through November and February through April, although there were important seasonal differences between sites. For example, the highest densities of Common Eider during fall were in a protected estuary, whereas abundance of scoters during fall was greater at a coastal headland. The relative activity of Common Eider on the water and in flight was similar among sites, whereas scoters exhibited highly variable activity among sites, particularly during winter and spring. The spatiotemporal patterns in abundance and behavior of sea ducks in nearshore waters that we detected using land-based surveys provides essential, complementary information to that available from other types of waterfowl and seabird surveys in southern New England.

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Key words.—Common Eider, *Melanitta*, migration, Rhode Island, scoters, sea duck distribution, *Somateria mollissima*.

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There is considerable interest in sea duck (Tribe Mergini) use of nearshore waters along the Atlantic and Pacific Coasts of North America because these areas provide very important wintering habitat that is potentially vulnerable to anthropogenic disturbance (Austin *et al.* 2014; Baldassarre 2014; De La Cruz *et al.* 2014). Nearshore areas are important to sea ducks because most species typically forage in shallow waters less than 20 m that often occur close to shore (Guillemette *et al.* 1993; Fox 2003). Much more is known about the large-scale distribution and abundance of sea ducks in winter along the western Atlantic Ocean (Zipkin *et al.* 2010; Silverman *et al.* 2013) than their distribution and abundance at more regional and local scales where sea ducks demonstrate their preferences for certain habitats (Johnson 1980), and their response to many environmental factors is determined. An understanding of sea duck distribution and abundance in nearshore areas at these finer scales is required to evaluate potential anthropogenic effects on local sea duck populations and inform local planning efforts (Madsen 1998; Langston 2013; De La Cruz *et al.* 2014; Winiarski *et al.* 2014).

Several studies have used aerial or boat-based surveys to assess the winter distribution and abundance of sea ducks at finer spatial scales (e.g., White *et al.* 2009; Winiarski *et al.* 2014). However, aerial and boat-based surveys are expensive, tend to be conducted infrequently, generally only occur when weather conditions are favorable for observation, often are not conducted near the coast for safety or regulatory considerations, and can have low detection probabilities for sea ducks (Camphuysen *et al.* 2002; Winiarski *et al.* 2013, 2014). Land-based surveys represent an alternative approach to monitor sea duck use patterns at fine spatial scales (McKinney *et al.* 2006; Loring *et al.* 2013). For example, the Avalon Sea Watch detects over 800,000 marine birds annually as they migrate off the coast of New Jersey (New Jersey Audubon Society, unpubl. data), and sea duck migration has been monitored from 1996-2012 at Point Lepreau in the Bay of Fundy (Bond *et al.* 2007; Cameron 2014). Unlike aerial and boat-based surveys, land-based surveys potentially provide a cost-effective method to document inter- and intra-annual spatial shifts in sea duck abundance and site-specific variation in behaviors (e.g., season-specific movements and flight paths) that are essential for detecting the potential effects of anthropogenic disturbances in nearshore habitats (Perry and Deller 1996; McKinney *et al.* 2006; Merkel *et al.* 2009).

We used land-based surveys in Rhode Island's nearshore waters to characterize spatiotemporal variation in the abundance and behavior of the most common species of sea ducks in the region including Common Eider (*Somateria mollissima*) and Black (*Melanitta americana*), Surf (*M. perspicillata*), and White-winged (*M. deglani*) scoters. We assessed variation in sea duck abundance, distribution, and behavior (e.g., foraging, flying) on diurnal and intra-annual (seasonal) temporal scales.

Methods

Study Area

We surveyed for sea ducks along the southern Rhode Island coast at 11 land-based point count sites along four survey routes from Watch Hill (41° 18′ N, 71° 51′ W) to Goosewing Beach in Little Compton (41° 28′ N, 71° 09′ W; Fig. 1) from February 2009 through July 2010. Three survey routes contained three sites, while the eastern-most route comprised two sites. We estimated the area of visible water for each site using a viewshed analysis (Environmental Systems Research Institute 2011) on 1-m horizontal resolution LiDAR data (U.S. Geological Survey 2012). The viewsheds of adjacent count sites overlapped considerably at four sites; therefore, we classified Beavertail and Brenton Point as one site, and Sachuest Point and Sakonnet Point as another site; this reduced the number of distinct "sites" in our statistical models to nine (Fig. 1).

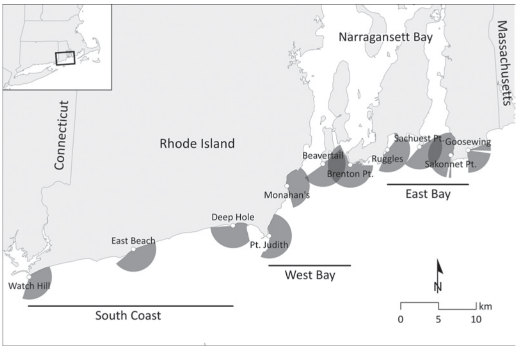

Figure 1. Sites where land-based surveys for sea ducks were conducted in coastal Rhode Island from February 2009 through July 2010. Sites were segregated into the southern coast (South Coast), western Narragansett Bay (West Bay), and eastern Narragansett Bay (East Bay). Gray polygons represent the estimated viewshed surveyed from each site; dark gray areas indicate regions of survey overlap between adjacent sites.

Surveys

We conducted surveys during mornings (AM: concluded before solar noon) and afternoons (PM: initiated after solar noon). During AM surveys, we surveyed the first site along each route for 120 min starting at dawn and subsequent sites for 60 min. For PM surveys, we surveyed the last site for 120 min and all preceding sites for 60 min. The surveys at dawn and dusk were longer to ensure adequate observation effort when activity of sea ducks was expected to be greatest. The exception to this pattern occurred in our first month of surveys due to logistical limitations – some February 2009 surveys were of intermediate length (typically 90 min) and most occurred during the morning. We varied the visitation order of sites along a route to better distribute the sampling times among sites. Survey effort varied from two to 10 monthly surveys at a given site, typically with two to four surveys per month in each AM/PM window (Fig. 2).

During each survey, a single observer recorded all sea ducks within 3 km of the count location (Fig. 1) and their location as on the ocean's surface (hereafter, "on the water") or in flight. Observers surveyed the ocean surface and airspace with a 20-60x spotting scope and 10x42 binoculars and recorded the number and species for all individuals or flocks during the survey period. We took care to avoid recounting sea ducks on the water during the observation period, and those in flight were visually tracked to confirm that they exited the viewshed. We recorded observations in the field using a handheld personal digital assistant.

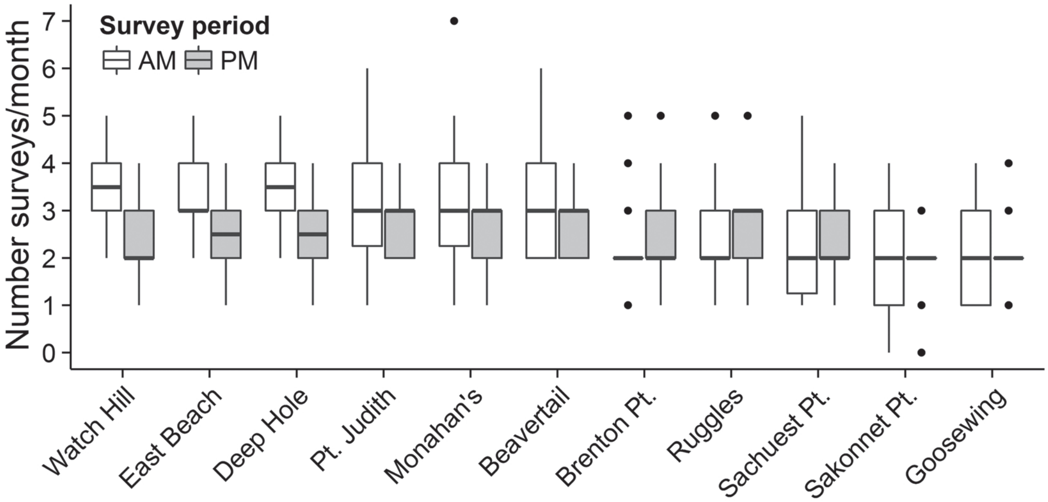

Figure 2. Summary of monthly survey effort (median and interquartile range) for land-based sea duck surveys by period (AM: morning; PM: afternoon) at 11 sites along the Rhode Island coast from February 2009 through July 2010.

We considered two species groups: Common Eider (hereafter, eider) and Surf, Black, and White-winged scoters (50%, 42%, and 8% of individuals identified to species, respectively; hereafter, scoters). We analyzed scoters collectively as they were often difficult to distinguish at a distance (50% were not assignable to species). We focused on eider and scoters as they represented nearly 75% of all sea ducks we observed. Long-tailed Ducks (*Clangula hyemalis*) and Red-breasted Mergansers (*Mergus serrator*) were infrequently observed during these surveys, and thus were excluded from analyses.

Adjusting for Survey Duration and Area Surveyed

We recorded most individuals observed initially on the water in the first 60 min of observation; whereas, previously uncounted flying individuals regularly entered the viewshed throughout a given survey. Thus, count duration was included as a fixed offset only in the models for flying sea ducks to account for "effort" effects on these counts. Because we counted few additional sea ducks on the water after the initial 60 min of a survey, we did not adjust for survey length in the models of sea ducks on the water. We included the area surveyed (i.e., viewshed area) as a covariate rather than a fixed offset because of the disproportionate addition of areas at longer ranges (i.e., 2-3 km), where fewer observations occurred.

Statistical Analysis

We used generalized additive models (GAMs; Hastie and Tibshirani 1990) to evaluate spatiotemporal variation in sea duck abundance and behavior. We created separate negative binomial GAMs for each species group and initial observation location (i.e., on the water or in flight). We allowed sea duck abundance to vary smoothly over daylight hours (i.e., proportion of daylight elapsed at the midpoint of each survey) using a penalized cubic regression spline. For seasonal patterns, we used a cyclic cubic regression spline that allowed sea duck abundance to vary smoothly over the course of the year. We preserved the association among consecutive fall migration, winter, and spring migration seasons by considering observations from 15 August to the subsequent 14 August as occurring in the same "year." We allowed separate seasonal splines for each of the nine "sites." We included a categorical covariate to accommodate potential differences in the two (partial) years that surveys occurred.

We could not incorporate temporal autocorrelation among counts in our GAMs due to convergence problems associated with fitting separate smoothing splines for each site. As countermeasures, however, we restricted the basis dimension of the spline terms and imposed an extra penalty to each term in the model (Marra and Wood 2011) and interpreted marginally important parametric effects with care. We fitted GAM models using the mgcv (Wood 2006, 2011) and nlme packages (generalized additive mixed models; Pinheiro *et al.* 2014) in statistical program R (R Development Core Team 2014).

We did not adjust statistically for differences in sea duck detection because we recorded only initial distances for sea ducks on the water or in flight. Conventional distance sampling methods typically fail for land-based surveys of the marine environment (Marques *et al.* 2010), and the techniques for separating the detection process from the expected non-uniformity in animal density (e.g., associated with bathymetry) additionally require the angle of detection (Cox *et al.* 2013). Thus, to compare abundances among sites, we necessarily assumed similar patterns of sea duck detection and density with distance from shore among sites. We varied the order of site visitations, viewsheds were similarly proportioned among sites, and the conditions most likely to impact detectability (e.g., wave height, atmospheric visibility, observers) varied similarly over time at each site. Nonetheless, we acknowledge that comparison of sea duck abundances among sites represented the combined effects of the actual abundance of sea ducks as well as the imperfect detection process.

RESULTS

Diurnal Variation

The density of eider and scoters on the water varied little during daylight hours (Fig. 3A). In contrast, eiders and scoters in flight were considerably more common during the first 25% of daylight hours compared to the rest of the day; sea duck flight activity varied little after mid-day (Fig. 3B).

Seasonal Variation

In general, we observed most flying eider and scoters in two distinct periods that likely represented fall and spring migratory movements through Rhode Island (Fig. 4). For both species groups, fall flight activity occurred primarily from October through November. During the fall migratory period, densities of flying eider were usually highest at sites near the western mouth of Narragansett Bay (Fig. 4A-C). Densities of scoters in flight during fall were greatest at Pt. Judith (Fig. 4E) and in late fall at East Beach (Fig. 4D). In the spring, flight activity occurred mostly from February through April, although we regularly detected scoters in flight into May. Estimated eider abundance in flight was lower during spring migration than fall at most sites, with peak abundances in spring at Beavertail/Brenton and Sachuest/Sakonnet (Fig. 4C). Scoter abundance during spring in flight was greatest at eastern Rhode Island at Sachuest/Sakonnet and Ruggles (Fig. 4F).

Sea ducks in flight were generally less abundant in winter relative to the migratory periods. However, we observed unusually high densities of flying eider at Watch Hill (Fig. 4A) and flying scoters at East Beach (Fig. 4D); neither of these sites experienced corresponding increases in the respective species on the water.

Relative densities of eider on the water (resting or foraging; Fig. 5A-C) corresponded generally to relative densities of individuals in flight during the migratory periods (Fig. 4A-C). Sites near the western mouth of Narragansett Bay and at Deep Hole experienced the greatest densities of eiders on the water during fall. In spring, sites in eastern Rhode Island (eastward from the Beavertail/Brenton Point area) consistently hosted more foraging eider (Fig. 5A-C); East Beach was a notable exception to this spring pattern, hosting a relatively high density of foraging eider in late winter that persisted into the early spring migratory period. Foraging

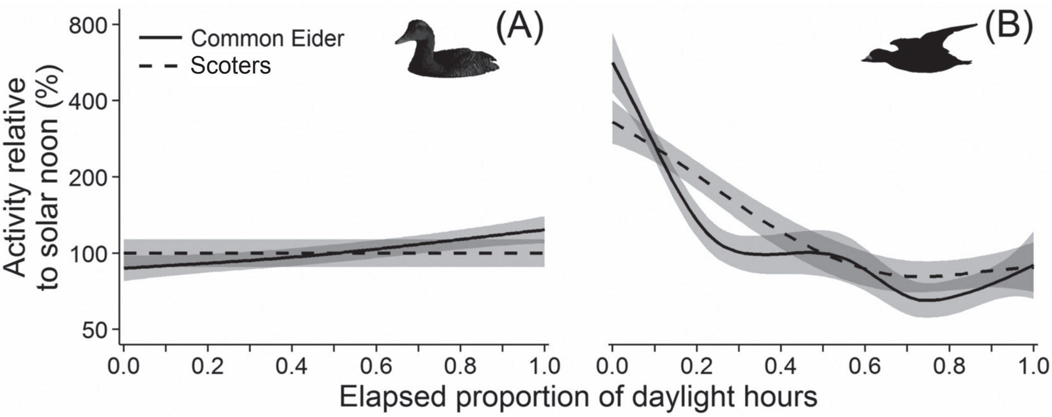

Figure 3. Diurnal variation in the (A) estimated density (individuals/km^2) of sea ducks on the water relative to that at solar noon and (B) estimated passage rates (individuals/km^2/hr) of flying sea ducks relative to that at solar noon for Common Eider and Black, Surf, and White-winged scoters (Scoters) during land-based surveys from February 2009 through July 2010 based on generalized additive models. A value of 100% indicates an estimated sea duck density similar to that at solar noon. Gray polygons represent the point-wise standard error of the fitted relationship.

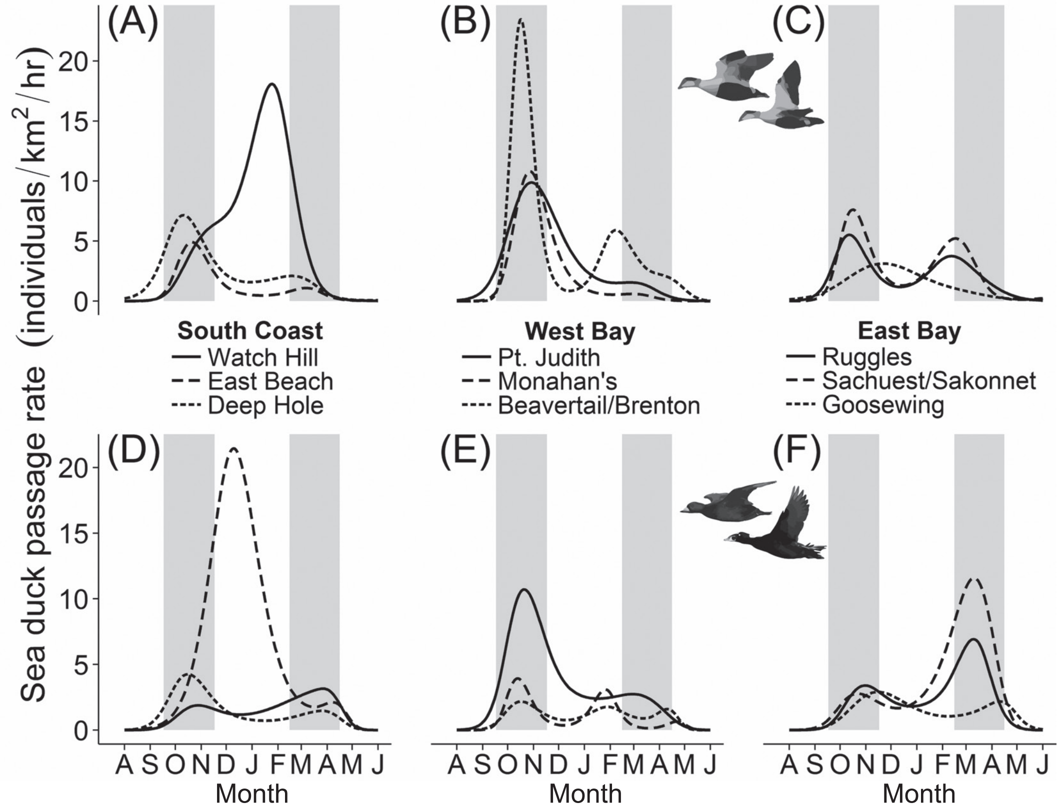

Figure 4. Seasonal variation (August through June) in the expected passage rate (individuals/km^2/hr) of flying (A-C) Common Eider and (D-F) Black, Surf, and White-winged scoters at nine sites in southern Rhode Island based on generalized additive models. Sites were grouped into three geographic regions (see Fig. 1): South Coast (A, D), West Bay (B, E), and East Bay (C, F); background shading indicates presumed fall and spring migratory periods.

eider were consistently present in greater densities in the Beavertail/Brenton Point area during winter, although eider densities increased late in the winter period at East Beach and the Sachuest/Sakonnet Point area (Fig. 5A-C).

Densities of scoters on the water (Fig. 5D-F) corresponded less well to patterns of flying scoters (Fig. 4D-F). At a given site, densities of scoters on the water were strictly unimodal (Fig. 5D-F), failing to exhibit the scoters' bimodal pattern of density in flight (corresponding to migratory periods; Fig. 4D-F) or eider on the water (Fig. 5A-C). Densities of scoters on the water were uniformly low during fall migration, except at Pt. Judith, contrasting with highly variable abundance among sites during the winter and spring migration. The areas experiencing the highest winter densities of foraging scoter (Watch Hill, Beavertail/Brenton Point, and Ruggles) were scattered along the Rhode Island coast (Fig. 5A-C). During spring migration, Ruggles hosted consistently greater densities of scoters on the water, although Watch Hill and Beavertail/Brenton Point retained relatively high densities early into the spring migration period (Fig. 5A-C).

DISCUSSION

The spatiotemporal patterns in abundance and behavior of sea ducks that we detected using land-based surveys provide essential information not otherwise available from other types of waterfowl and seabird surveys in southern New England. Prior to these land-based surveys, few quantitative studies existed on the spatial distribution and abundance of sea ducks in the region.

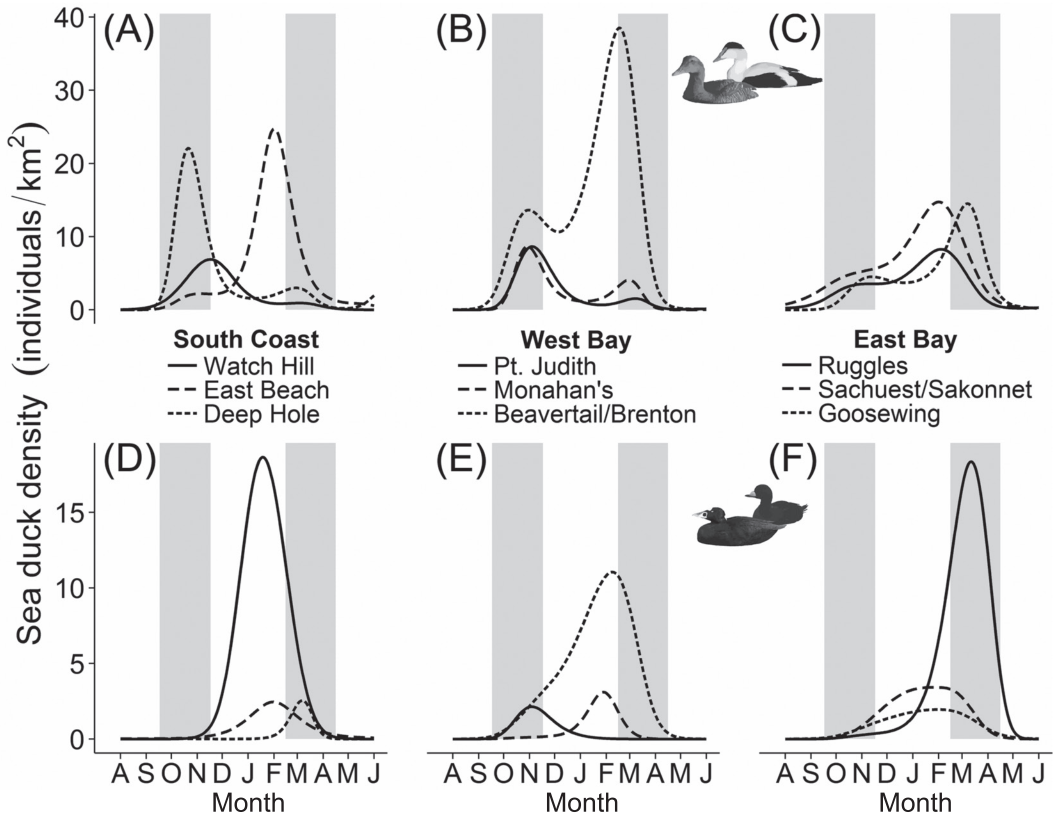

Figure 5. Seasonal variation (August through June) in the expected density (individuals/km^2) of (A-C) Common Eider and (D-F) Black, Surf, and White-winged scoters detected on the ocean surface at nine sites in southern Rhode Island based on generalized additive models. Sites were grouped into three geographic regions (see Figs. 1 and 4).

In southern New England, the mid-winter waterfowl aerial survey, conducted once annually by Rhode Island Department of Environmental Management, does not survey nearshore areas where most sea ducks concentrate (J. Osenkowski, unpubl. data). Winiarski *et al.* (2014) conducted aerial and boat-based surveys throughout Rhode Island and Block Island Sounds, but nearshore habitats were not sampled due to Federal Aviation Administration restrictions and water depth constraints for larger survey ships. Therefore, the results from our land-based surveys provide valuable baseline information on fine-scale spatiotemporal dynamics of sea ducks of nearshore waters in the region. This type of information will be useful for planners interested in minimizing effects to local sea duck populations from anthropogenic disturbance, such as offshore wind energy facilities, by determining where the highest concentrations of sea ducks and other marine birds are located (Langston 2013; De La Cruz *et al.* 2014).

We detected substantially greater numbers of birds in flight near sunrise, which concurs with other land-based surveys in the western Atlantic (Bond *et al.* 2007; Cameron 2014). Therefore, biologists interested in potential collision risk with wind turbines and other objects should conduct surveys of flight activity during the first 3 hours after sunrise. Increased flight activity near sunrise presumably includes movements from offshore nocturnal roosts to nearshore foraging areas (e.g., Lewis *et al.* 2005). However, we did not detect increased flight activity near sunset, which suggests that movements from nearshore foraging sites to offshore roosts in southern Rhode Island occurs after sunset or via swimming (Mudge and Allen 1980; Reed and Flint 2007).

Peak numbers of flying sea ducks during fall and spring corroborated the presumed migratory periods throughout the region (Veit and Petersen 1993; Beuth 2013; Baldassarre 2014; Loring *et al.* 2014), including the slightly extended spring migratory period for scoters relative to eider. Most sites exhibited a bimodal annual cycle, with peak numbers of eider and scoters in flight in fall and spring. Due to the orientation of the coastline in southern Rhode Island, most sea ducks migrated east or west in this area. Therefore, we did not expect the abundance of sea ducks in flight to vary substantially among sites during migratory periods. The variation documented among sites suggests that monitoring a single site may be insufficient to capture variation in local (e.g., wintering) sea duck abundance and distribution, although a single site may be sufficient to monitor their general migratory movements (e.g., Cameron 2014).

Land-based surveys of nearshore environments complement existing standardized sea duck surveys along the Atlantic Coast, such as the aerial surveys conducted along much of the Atlantic Coast (Zipkin *et al.* 2010; Silverman *et al.* 2013) or at smaller spatial scales (Winiarski *et al.* 2014). We suggest that systematic, multi-site land-based surveys fill an important gap in aerial and boat-based surveys: they document the dynamics of sea duck abundance and distribution in important nearshore areas missed by most aerial surveys and single-site migration counts. This information can inform regional conservation planning (e.g., harvest management: Merkel 2004; placement of offshore wind turbines: Langston 2013). Furthermore, while satellite telemetry provides important movement and migratory connectivity details (Beuth 2013; Loring *et al.* 2014), inferences of resource selection from satellite telemetry typically require broad generalizations from relatively small samples of individuals that may not have been representatively sampled from the population. Land-based surveys could facilitate the evaluation of resource selection and anthropogenic disturbance at the population rather than individual level.

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