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Research Paper

Exposure of Whimbrels to offshore wind leases during departure from and arrival to a major mid-Atlantic staging site

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ABSTRACT. The United States is pursuing a diversified energy portfolio that includes offshore wind with a focus on the Atlantic Outer Continental Shelf (OCS). The Western Atlantic Flyway (WAF) supports one of the largest near-shore movement corridors of birds in the world, including several shorebird species of high conservation concern. We used satellite transmitters to examine orientation of Whimbrels (*Numenius phaeopus*) crossing the OCS and their overlap with two wind energy leases. Birds using a migratory staging site along the Delmarva Peninsula in Virginia crossed the OCS along a southeast-northwest axis. A considerable percentage (42.9%) of tracks intersected with one of the two wind leases. The juxtaposition to the Delmarva Peninsula placed wind leases southeast of the peninsula within both the departure and arrival trajectories of Whimbrels. The satellite transmitters used in this study were not equipped with altitude sensors, so we do not know if birds crossed wind leases within the rotor swept zone. Several species of shorebirds, including hundreds of thousands of individuals, make trans-Atlantic flights from three major staging sites: Delaware Bay, the lower Delmarva Peninsula, and Georgia Bight. All of these sites have wind leases positioned to their southeast. One of the most effective strategies for minimizing conflicts between birds and potential hazards is to place hazards away from critical movement corridors. More information is needed about departure and arrival patterns of shorebirds that cross the OCS to inform future lease placement.

Exposition de Courlis corlieu aux concessions d'éoliennes en mer pendant le départ et l'arrivée à une importante halte migratoire du milieu de la côte atlantique

RÉSUMÉ. Les États-Unis cherchent à diversifier leur portefeuille énergétique, en y incluant l'énergie éolienne en mer, dont sur le plateau continental externe (PCE) de l'Atlantique. La voie de migration de l'Atlantique ouest soutient l'un des plus grands corridors de déplacement d'oiseaux près des côtes au monde, y compris plusieurs espèces d'oiseaux de rivage dont la conservation est très importante. Nous avons utilisé des émetteurs satellitaires pour examiner la direction que prennent les Courlis corlieu (*Numenius phaeopus*) traversant le PCE et leur chevauchement avec deux concessions d'énergie éolienne. Les oiseaux utilisant une halte migratoire le long de la péninsule de Delmarva, en Virginie, ont traversé le PCE selon un axe sud-est-nord-ouest. Un pourcentage considérable (42,9 %) des trajectoires croisait l'une des deux concessions éoliennes. Les concessions éoliennes au sud-est de la péninsule de Delmarva se trouvaient dans les trajectoires de départ et d'arrivée des Courlis corlieu. Les émetteurs satellitaires utilisés n'étant pas équipés de capteurs d'altitude, nous ne savons pas si les oiseaux ont traversé les concessions éoliennes à la hauteur de la zone de balayage du rotor. Plusieurs espèces d'oiseaux de rivage, dont des centaines de milliers d'individus, effectuent des vols transatlantiques à partir de trois principales haltes migratoires : la baie du Delaware, la partie inférieure de la péninsule de Delmarva et la baie de Géorgie. Tous ces sites ont des concessions éoliennes positionnées au sud-est. L'une des stratégies les plus efficaces pour minimiser les conflits entre les oiseaux et les dangers potentiels est de placer les dangers loin des corridors de déplacement essentiels. Il est nécessaire d'obtenir plus d'informations sur les tendances de départ et d'arrivée des oiseaux de rivage qui traversent le PCE afin d'éclairer les futurs emplacements de concessions.

Key Words: *Numenius phaeopus; offshore wind; outer continental shelf; satellite tracking; Western Atlantic Flyway; Whimbrel*

INTRODUCTION

Along with many nations throughout the world, the United States is actively pursuing a diversified energy portfolio that includes a greater reliance on clean, renewable sources of domestic energy. Offshore wind represents a significant component of this renewable energy strategy. The Atlantic Coast offers abundant wind resources and shallow, near-shore waters in close proximity to large electricity load centers with some of the most lucrative and rapidly expanding energy markets in the country (Gilman et al. 2016). Near-shore waters (< 30 m depth) support enough potential wind energy that, if fully exploited, could displace the entire land-based generating capacity of the coastal states from Maine through Maryland (Energy Information Administration 2004, Musial et al. 2016). To facilitate the transition to renewable energy sources, the Bureau of Ocean Energy Management (BOEM) is accelerating access to the Atlantic Outer Continental Shelf (OCS) for the purpose of developing commercial-scale wind energy facilities. Currently, 7073 km² of the Atlantic OCS is under lease, with an additional 11,235 km² in the planning phase. Existing leases are widespread, extending along the coast from South Carolina north to Massachusetts (BOEM 2021). To date, development of offshore wind along the Atlantic Coast is limited

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to a 30-megawatt demonstration facility in state waters along Rhode Island and a 12-megawatt pilot project within the Atlantic OCS along Virginia.

The Western Atlantic Flyway (WAF) supports one of the largest near-shore movement corridors of birds in the world, annually hosting hundreds of millions of birds of over 160 species, many of which are of conservation concern (Watts 2010, Robinson Willmott et al. 2013). Waterbird populations using the flyway are drawn from breeding ranges across much of North America, funnel along the coast in a thin veneer over near-shore waters, and then fan out again to broadly dispersed winter ranges. In addition to serving as a movement corridor, portions of the Atlantic Coast serve as strategic staging sites where waterbirds stop for extended periods to rest and refuel before continuing their migration (e.g., Atkinson et al. 2007, Spiegel et al. 2017). Among the most prominent groups of waterbirds using the WAF are shorebirds. Of the 35 shorebird populations with trend data that regularly utilize the WAF, 65% are declining, whereas 11% are increasing (Andres et al. 2012).

Whimbrels (*Numenius phaeopus*) are large shorebirds that use the WAF during both spring and fall migration (Johnson et al. 2016, Skeel and Mallory 2020). Surveys within a spring staging site (Watts and Truitt 2011) and within the primary winter grounds (Morrison et al. 2012) indicate that Whimbrels using the WAF have experienced significant declines over the past three decades. Whimbrels exhibit delayed recruitment and have low reproductive potential (Watts et al. 2015). A recent assessment suggests that adult mortality rates are elevated above sustainable levels and are likely contributing to ongoing declines (Watts et al. 2019). As a consequence of these patterns and relatively small population sizes, Whimbrels have been assigned high conservation scores by both the United States and Canadian shorebird conservation plans (USCPP 2015, Hope et al. 2019).

Because of the low number of offshore wind facilities that have been built within the WAF, we have very little information about the actual impact of these hazards on shorebird populations. However, on the basis of studies with other waterbirds that have traits in common, shorebirds are likely to experience two types of impact from offshore facilities, collisions and displacement (Exo et al. 2003, Pearce-Higgins et al. 2009, Loss et al. 2013, Marques et al. 2014). Collisions may involve the physical turbine (vertical axis and rotor blades) or may involve the vortex near-wake (Jiguet et al. 2021) as birds fly through an operating turbine. Both of these risks require that birds are “exposed” to the hazard or occupy the same physical space. Collision rate is increased when turbines are placed within areas supporting high bird densities, such as migratory staging sites, and may be influenced by weather (Newton 2008, Loss 2016). Displacement occurs when individuals avoid areas supporting turbines (Pearce-Higgins et al. 2012, Niemuth et al. 2013). With respect to movements such as migration, avoidance behavior may require that individuals alter routes to move around wind farms, potentially costing more time and energy (Garthe and Hüppop 2004, Furness et al. 2013).

Because the greatest volume of shorebird migration within the WAF is believed to occur close to the coast (Loring et al. 2020), populations are expected to have relatively little exposure to wind leases located within the Atlantic OCS (5–320 km offshore). An exception to this pattern may be around major staging sites where birds initiate or end transoceanic flights that cross waters of the Atlantic OCS on their way to or from winter grounds within the Caribbean Basin or South America. Well-known shorebird staging sites that occur along the Atlantic Coast include Delaware Bay (Clark et al. 1993), the Delmarva Peninsula (Watts and Truitt 2001, 2011, 2014), and the Georgia Bight (Wallover et al. 2015, Lyons et al. 2018). Birds departing from or arriving to these staging sites are known to cross waters of the Atlantic OCS (Burger et al. 2012a, Loring et al. 2020, Watts et al. 2021a). Each of these sites has associated wind leases located within the Atlantic OCS. However, we know very little about the departure and arrival pathways and the extent to which these birds may be exposed to future wind energy development within existing leases. Here, we use satellite transmitters to track Whimbrels flying across the OCS as they depart from and arrive at a migratory staging site to evaluate their flight trajectory and potential exposure to two wind energy leases.

METHODS

Study Area

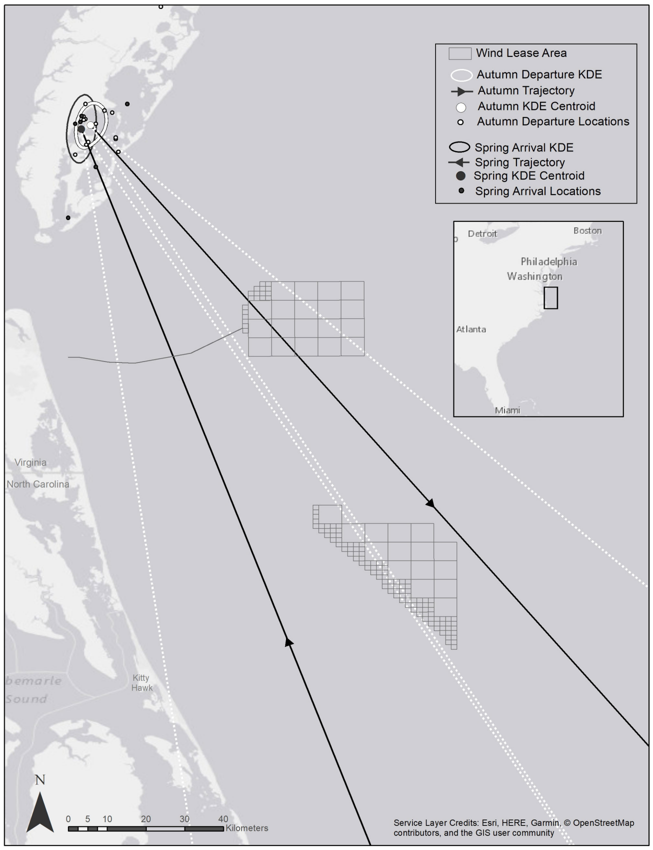
This study was conducted within a major spring and fall staging site for Whimbrels along the seaward margin of the lower Delmarva Peninsula in Virginia (Watts and Truitt 2011) and included two BOEM wind energy lease sites within the Atlantic OCS (Fig. 1). The lower Delmarva supports thousands to tens of thousands of Whimbrels during both the spring and fall migration periods (Watts and Truitt 2011). Whimbrels stage within the site for approximately 4 weeks before initiating the next leg of migration (Watts et al. 2021a). In addition to Whimbrels, the Delmarva Peninsula supports several other shorebird species of conservation concern during migratory periods (Watts and Truitt 2001, 2011, 2014) and has been designated as a UNESCO Biosphere Reserve (https://en.unesco.org/biosphere/wnbr) and a Western Hemisphere Shorebird Reserve Site with international status (http://www.whsrn.org), and is the site of a National Science Foundation Long-term Ecological Research site (https://lternet.edu/site/virginia-coast-reserve-lter/) and the focus of a multi-organizational partnership dedicated to bird conservation.

The two BOEM leases include a site offshore of Virginia Beach, Virginia (centered on 36.905 N, 75.365 W) and a site offshore of Kitty Hawk, North Carolina (centered on 36.338 N, 75.129 W). The Coastal Virginia Offshore Wind Project (OCS-A-0497) covers 45,649 ha and is positioned 37.9 km (closest point) east of the shoreline in the OCS. The site is leased by the Commonwealth of Virginia’s Department of Mines Minerals and Energy and is operated by Dominion Energy. Two test turbines were installed within this site in 2020. The Kitty Hawk Offshore Wind Project (OCS-A-0508) covers 49,537 ha and is positioned 38.7 km (closest point) east of the shoreline in federal waters. The site is leased to Avangrid Renewables, LLC. To date, no turbines have been constructed within this site.

Field Methods

We captured 10 Whimbrels between 2008 and 2012 on migratory staging sites along the lower Delmarva Peninsula in Virginia, USA ($n = 9$; 37.398 N, 75.865 W) and along the coast of Georgia, USA ($n = 1$; 31.148 N, 81.379 W). All birds were aged as adults by plumage (Prater et al. 1977, Pyle 2008) and were banded with

Fig. 1. Boundary maps of Virginia and North Carolina Bureau of Ocean Energy Management (BOEM) wind leases (OCS-A-0497 and OCS-A-0508, respectively) and autumn departure and spring arrival kernel density estimations (KDE) for Whimbrels (*Numenius phaeopus*) between 2008 and 2013. Track trajectories depict mean (solid lines) ± SE (dashed lines) of autumn departure and spring arrival bearings. Tracks were recorded for birds fitted with solar-powered satellite transmitters



United States Geological Survey tarsal bands and coded leg flags. Sex of captured birds was not determined.

We fitted all birds with satellite transmitters called Platform Transmitter Terminals (PTTs) using a modification of the leg-loop harness (Rappole and Tipton 1991, Sanzenbacher et al. 2000). Instead of an elastic cord, we used Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, USA) that was fastened with brass rivets or crimps (Watts et al. 2008). We glued transmitters to a larger square of neoprene to elevate it above the body and prevent the bird from preening feathers over the solar panels. The transmitter package was below 3% of body mass measured at the time of deployment (563.9 ± 20.6 g) for all individuals tracked in this study. The PTTs used in this study were 9.5 g PTT-100 solar-powered units produced by Microwave Telemetry, Inc. (Columbia, Maryland, USA).

Tracking

Birds were located by using satellites of the National Oceanic and Atmospheric Administration and the European Organization for the Exploitation of Meteorological Satellites with onboard tracking equipment operated by Collecte Localisation Satellites (CLS America, Inc., Largo, Maryland, USA; Fancy et al. 1998). Transmitters were programmed to operate with a duty cycle of 24 h off and 5 h on ($n = 9$) or 48 h off and 10 h on ($n = 1$) and collected 1–34 (= 5.48 ± 0.07) locations per cycle. Locations in latitude and longitude decimal degrees, date, time, and location error were received from CLS America within 24 h of satellite contact with PTTs. Locations were estimated by the Advanced Research and Global Observation Satellite (ARGOS) system (www.Argos-system.org), which uses a Doppler shift in signal frequency and calculates a probability distribution within which the estimate lies. The standard deviation of this distribution gives an estimate of the location accuracy and assigns it to a "location class" (LC): LC3, < 150 m; LC2, 150–350 m; LC1, 350–1000 m; LC0, > 1000 m; LCA, location based on 3 messages and has no accuracy estimate; LCB, location based on 2 messages and has no accuracy estimate; and LCZ, location process failed. We used LC classes 1–3 to determine the last Whimbrel locations before and after flights to and from the Delmarva Peninsula.

Departure and Arrival

We estimated the seasonality of potential exposure to lease areas by using departure and arrival dates, respectively, from and to the lower Delmarva staging site. We used tracking data to determine the dates of departure and arrival. We considered departure or the onset of migration to be when birds made decisive breakout movements away from the site. In order to identify these breakout movements, we first located the first and last Whimbrel location overlaying the Delmarva Peninsula and used these locations to develop centroids for each individual. We considered the first departure movement to be the first location that exceeded 2 standard deviation units beyond the mean of movements around centroids. We considered the dates of breakout movements to be the dates of departure. We considered arrival to be the dates of first locations overlaying the Delmarva Peninsula. In cases when departure and arrival times occurred outside the transmitter's duty cycle, we calculated the speed between the arrival or departure location and the last or next flight location. If the speed was less than 2 SDs below the mean Whimbrel flight speed (= 14.7 ± 0.3 m/s, $n = 45$; Watts et al. 2021a), we interpolated arrival and departure times by using the mean Whimbrel flight speed and great circle distance between the two points. Departure and arrival were both abrupt and we recorded no aborted attempts at migration.

We delineated departure and arrival areas within the staging site. We considered the last location prior to departure and first location after arrival to represent locations of departure and arrival. We mapped all departure and arrival locations using a kernel density estimator (KDE) method (Worton 1995) with the "ks" package (Duong 2007) in program R (R Core Team 2020). We used the normal (or Gaussian) kernel and a smooth cross-validation bandwidth selector (Duong and Hazelton 2005) to map 50% kernel densities. We considered the 50% KDE to be the area of highest departure and arrival activity. We estimated the centroid of KDE polygons for departure and arrival using the package "geosphere" (Hijmans et al. 2021) in Program R (R Core Team 2020).

We used tracking data to delineate migratory pathways to and from the Delmarva Peninsula. We considered pathways to include the route traveled between the location of departure or arrival and the arrival or departure location on the winter grounds. Because of the duty cycle of the transmitters our dataset had temporal gaps in coverage. We filled these gaps using continuous-time correlated random walk (CRAWL) models (Johnson et al. 2008, Johnson et al. 2018) in Program R (R Core Team 2020) that allowed us to interpolate a pathway for each individual. We used the segment of the migratory pathway for each individual that extended from the departure or arrival location to the first point east or south of wind leases to determine the direction (degrees) of travel for birds departing from or arriving to the staging site. We also determined the angle of juxtaposition between departure and arrival areas and wind leases by estimating the bearing between KDE polygon centroids and centroids of wind leases. All bearings were determined in ArcGIS Desktop 10.7.1 (Environmental Systems Research Institute, Inc. 1999–2010).

Exposure to BOEM Leases

We examined exposure of Whimbrels to BOEM wind leases by using tracking data. We overlaid individual tracks on polygons of both lease sites to determine the frequency of overflights during both autumn and spring migrations. We considered tracks to have overflown a lease if the track overlapped any portion of the lease. We projected mean flight lines (± SE) from stopover centroids. We overlaid individuals' flight lines on polygons of wind leases and calculated the proportion (estimated percentage of population) of birds that overflew the polygons as an estimate of population-level exposure.

Statistics

We developed descriptive statistics, including means and standard errors, for departure and arrival dates and directions of travel. We tested for patterns in directionality of departure and arrival using the Rayleigh uniformity test (Berens 2009). We compared orientation of autumn departure and spring arrival using Welch's t-test to accommodate unequal sample sizes.

RESULTS

Whimbrel departure and arrival positions were located within the lagoon system of the lower Delmarva Peninsula and were generally consistent between autumn and spring seasons (Fig. 1). Birds departed the staging site in autumn (n = 15) moving along a southeast bearing (Fig. 2a) and exhibited significant directionality (mean bearing = 144 ± 7.9°, = 0.88, p < 0.001). Birds arrived (n = 6) on the staging site moving along a northwest bearing (Fig. 2b) and also exhibited significant directionality (mean bearing = 342 ± 10.9°, back azimuth = 162 ± 10.9°, = 0.91, p = 0.002). Although the orientation of spring arrival was more north-south compared to fall departure, the 20° difference was not statistically significant (t = -1.33, df = 11, p = 0.21). The juxtaposition of the wind leases and the departure/arrival KDEs is in agreement with these bearings (Table 1), which suggests that many Whimbrels departing the Delmarva Peninsula migrate along routes that pass through these wind lease areas. Distances between departure/arrival centroids and centroids of wind leases ranged from 66 to 131 km (Table 1).

Fig. 2. Frequency distribution of orientation (bearings) of Whimbrels (*Numenius phaeopus*) tracked departing in the autumn (n = 15) from (2a) and arriving in the spring (n = 6) to (2b) the lower Delmarva Peninsula, Virginia, USA staging site between 2008 and 2013. Arrows represent the mean bearings for autumn departures and spring arrivals. Bearings in the spring represent the back-azimuth of travel to better relate the orientation relative to wind leases.

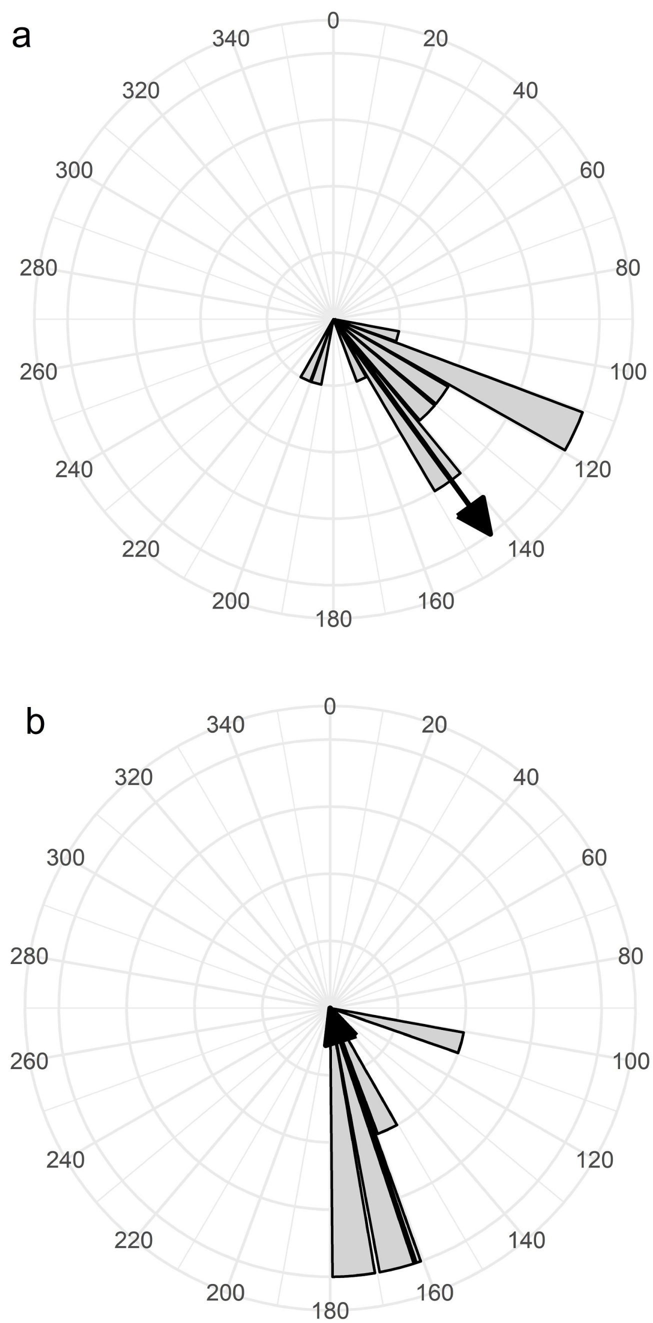


Table 1. Orientation and distance between staging (autumn and spring) centroids on the lower Delmarva Peninsula and wind leases off the coast of Virginia and North Carolina. Autumn departure (n = 15) and spring arrival (n = 6) reflect locations for Whimbrels (*Numenius phaeopus*) tracked with satellite transmitters that staged along the lower Delmarva Peninsula in Virginia between 2008 and 2013. Overflight reflects the % of tracked birds that flew over the leases during either autumn or spring.

Juxtaposition	Orientation (°)	Distance (km)	Overflight (% of total)
Autumn departure			
Virginia lease	140	66.4	40.0
North Carolina lease	150	130.6	13.3
Spring arrival			
Virginia lease	138	67.0	0
North Carolina lease	150	130.7	16.7

Tracked Whimbrels crossed the Atlantic OCS 21 times, 15 in the autumn and 6 in the spring. A total of 9 (42.9%) of these tracks overflew wind leases, 6 over the Virginia lease and 3 over the North Carolina lease. There is some evidence that Whimbrels departing the staging site (6 of 15 overflew the lease) may have higher exposure to the Virginia wind lease compared to Whimbrels arriving (0 of 6 overflew the lease) in the spring (G-statistic = 2.12, $df = 1$, $p = 0.07$). This may be expected because the autumn trajectory has a more east-west component compared to the spring trajectory. However, the small sample size limits our ability to resolve possible lease site by season patterns.

Whimbrels crossed the Atlantic OCS during relatively narrow time windows in early autumn and spring. Birds departed from the lower Delmarva staging site from 23 July through 19 September (= 24 August ± 4 days SE) during autumn migration, though the earliest departure occurred 13 days prior to the next earliest departure. Birds arrived on site from 5 April through 6 May (= 17 April ± 5 days), though four arrivals occurred from 5 April to 13 April and two later arrivals occurred on 29 April and 6 May.

DISCUSSION

Whimbrels using the lower Delmarva staging site followed a consistent direction during departure and arrival. This finding is in agreement with numerous other studies that have examined the orientation of departure and arrival flights of shorebirds using major staging sites (e.g., Richardson 1979, Piersma et al. 1990, Battley et al. 2012, Tan et al. 2018). During both seasons, Whimbrels followed a southeast-northwest axis with a more easterly component during autumn departure. This finding is consistent with the position of the lower Delmarva relative to the primary winter grounds along the northern coast of South America and what we know about the orientation of migratory pathways. Whimbrels stage along the lower Delmarva in autumn, make a transoceanic flight to winter grounds along the northern coast of South America, depart the winter grounds in early spring, and make a transoceanic flight back to the lower Delmarva to stage during the spring (Johnson et al. 2016, Watts et al. 2021b). The pattern observed in Whimbrels is consistent with a generalized southeast orientation for shorebirds leaving the Atlantic Coast in fall to make transoceanic flights to winter grounds that has been documented for several species (Loring et al. 2020).

Several authors have emphasized the need to use information on activities and movement of shorebirds to inform the planning of wind facilities in order to minimize potential impacts (O'Connell et al. 2011, Burger et al. 2012b, Howell et al. 2020). Of particular interest are departure and arrival pathways around staging sites where ascent or descent may expose shorebirds to hazards. The location of the Virginia and North Carolina wind leases are southeast of the lower Delmarva staging site and within the flight lines for both departure and arrival. More than 40% of the tracks that crossed the Atlantic OCS flew over one of the leases, suggesting that birds would have had exposure to turbines constructed within the leases. Because of the differences in orientation between autumn and spring it appears that birds may have greater exposure to the Virginia wind lease during departure compared to arrival. Additional information is required to evaluate the possible influence of season on risk. Ninety-five percent of Whimbrels are expected to arrive in spring between 26 March and 12 May and depart in autumn between 1 August and 17 September (Watts et al. 2021a).

Flight altitude is believed to be one of the largest determinants of collision risk for birds crossing wind facilities (Fox et al. 2006, Fijn et al. 2015). The satellite transmitters used in this study were not equipped with altitude sensors because of weight constraints, so we do not know if birds crossed wind leases within the rotor swept zone (RSZ, 25–250 m). Galtbalt et al. (2021) found that Whimbrels using the Australasian migratory pathway fly over ocean at relatively low altitudes (median altitude = 138 m). Piersma et al. (1990) examined climbing rates of eight shorebird species departing from the Banc d' Arguin and found Whimbrels to have the lowest ($0.21\ ms^{-1}$) climbing rate. Some birds had not moved beyond the RSZ by the time they could no longer be observed (1.5 km). This pattern is consistent with observations of some Whimbrel flocks leaving the lower Delmarva staging site in spring (Watts et al. 2017) that do not rise above the RSZ before flying out of site (Wilke, *unpublished data*). Loring et al. (2020) modeled flight altitudes of shorebirds crossing the OCS and found that most were above the RSZ, although values varied greatly, and 24% and 36% were within the RSZ during spring and fall, respectively. Migration altitude is known to be influenced by several factors, including wind direction, precipitation, and time of day (e.g., Eastwood and Rider 1965, Shamoun-Baranes et al. 2006, Lindström et al. 2021). Although additional work is needed to determine the altitude of Whimbrels flying over the Virginia and North Carolina wind lease sites, variation in flight altitudes observed in shorebirds in general suggest that some Whimbrels are likely crossing through the RSZ.

The position of the Virginia and North Carolina wind leases southeast of the lower Delmarva staging site is not unique (Loring et al. 2020). The other two major shorebird staging sites along the south Atlantic Coast, Delaware Bay and the Georgia Bight, also have wind leases positioned to their southeast. Collectively, these three staging sites support significant portions of entire shorebird populations of several species that, like Whimbrels, make trans-Atlantic flights to and from winter grounds. Prominent species supported within these sites that depart and arrive over the OCS are Black-bellied Plover (*Pluvialis squatarola*), Semipalmated Plover (*Charadrius semipalmatus*), Lesser Yellowlegs (*Tringa flavipes*), Ruddy Turnstone (*Arenaria interpres*), Red Knot (*Calidris canutus*), Semipalmated Sandpiper (*Calidris pusilla*), and Short-billed Dowitcher (*Limnodromus griseus*; Loring et al. 2020). These species likely take trajectories similar to those of Whimbrels during autumn departure and spring arrival and may have significant exposure to wind leases associated with these staging sites.

One of the most effective strategies for mitigating the impact of wind facilities placed within the OCS is to locate facilities away from bird activity centers. Although most bird species migrate along a north-south axis over nearshore waters, some shorebird species that make trans-Atlantic flights between coastal staging sites and winter grounds cross the OCS. Such crossings are concentrated around major staging sites. For Whimbrels using the lower Delmarva site, these flights have a consistent southeast-northwest orientation that results in overflight of downstream wind leases. A similar juxtaposition occurs with wind leases near other coastal staging sites. Because populations of high conservation concern depend on these sites, consideration should be given to locating wind leases north or south of these movement corridors. For offshore wind facilities that have been approved or built, options to mitigate collision risk are primarily operational, including seasonal or time of day restrictions. The seasonality of spring arrival and autumn departure is known for Whimbrels along the Atlantic Coast (Watts et al. 2021a) and this information could be used to inform the schedule of operations in an effort to reduce collision risk. Whimbrel departure from staging areas has been shown to be highly concentrated within a two-hour window (1.5 to 3.5 h before twilight) of the day (Watts et al. 2017). This information could be used to further refine operations. Although birds did overfly wind leases, we do not know their flight altitude. A research priority is to collect altitude data for birds to improve our understanding of vertical exposure to offshore wind turbines.

Responses to this article can be read online at:
https://www.ace-eco.org/issues/responses.php/2312

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Bryan D. Watts - conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, writing Chance Hines - Formal Analysis, methodology, review Laura Duval - project administration, review Alexandra L. Wilke - Conceptualization, review

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LITERATURE CITED

Andres, B. A., P. A. Smith, R. I. G. Morrison, C. L. Gratto-Trevor, S. C. Brown, and C. A. Friis. 2012. Population estimates of North American shorebirds. Wader Study Group Bulletin 119 (3):178-194.

Atkinson, P. W., A. J. Baker, K. A. Bennett, N. A. Clark, J. A. Clark, K. B. Cole, A. Dekinga, A. Dey, S. Gillings, P. M. Gonzalez, K. Kalasz, C. D. T. Minton, J. Newton, L. J. Niles, T. Piersma, R. A. Robinson, and H. P. Sitters. 2007. Rates of mass gain and energy deposition in Red Knot on their final spring staging site is both time- and condition-dependent. Journal of Applied Ecology 44(4):885-895. https://doi.org/10.1111/j.1365-2664.2007.01308.x

Battley, P. F., N. Warnock, T. L. Tibbitts, R. E. Gill, Jr., T. Piersma, C. J. Hassell, D. C. Douglas, D. M. Mulcahy, B. D. Gartrell, R. Schuckard, D. S. Melville, and A. C. Riegen. 2012. Contrasting extreme long-distance migration patterns in Bar-tailed Godwits *Limosa lapponica*. Journal of Avian Biology 43:21-32. https://doi.org/10.1111/j.1600-048X.2011.05473.x

Berens, P. 2009. CircStat: a MATLAB toolbox for circular statistics. Journal of Statistical Software 31(10):1-21. https://doi.org/10.18637/jss.v031.i10

Bureau of Ocean Energy Management (BOEM). 2021. Renewable energy GIS data. BOEM, U.S. Department of the Interior, Washington, D.C., USA. https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data

Burger, J., L. J. Niles, R. R. Porter, A. D. Dey, S. Koch, and C. Gordon. 2012a. Migration and over-wintering of Red Knots (*Calidris canutus rufa*) along the Atlantic Coast of the United States. Condor 114(2):302-313. https://doi.org/10.1525/cond.2012.110077

Burger, J., L. J. Niles, R. R. Porter, A. D. Dey, S. Koch, and C. Gordon. 2012b. Using a shore bird (Red Knot) fitted with geolocators to evaluate a conceptual risk model focusing on offshore wind. Renewable Energy 43:370-377. https://doi.org/10.1016/j.renene.2011.11.006

Clark, K., L. Niles, and J. Burger. 1993. Abundance and distribution of shorebirds migrating on Delaware Bay. Condor 95(3):694-705. https://doi.org/10.2307/1369612

Duong, T. 2007. ks: Kernel density estimation and kernel discriminant analysis for multivariate data in R. Journal of Statistical Software 21(7):1-16. https://doi.org/10.18637/jss.v021.i07

Duong, T., and M. L. Hazelton. 2005. Cross-validation bandwidth matrices for multivariate kernel density estimation. Scandinavian Journal of Statistics 32(3):485-506. https://doi.org/10.1111/j.1467-9469.2005.00445.x

Eastwood, E., and G. C. Rider. 1965. Some radar measurements of the altitude of bird flights. British Birds 58(10):393-426.

Energy Information Administration. 2004. State electricity profiles 2002. United States Department of Energy, Washington, D.C., USA.

Exo, K. M., O. Hüppop, and S. Garthe. 2003. Birds and offshore wind farms: a hot topic in marine ecology. Wader Study Group Bulletin 100:50-53.

Fancy, S. G., L. F. Pank, D. C. Douglas, C. H. Curby, G. W. Garner, S. C. Amstrup, and W. I. Regelin. 1988. Satellite telemetry: a new tool for wildlife research and management. United States Fish and Wildlife Service Resource Publication 172. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Fijn, R. C., K. L. Krijgsveld, M. J. M. Poot, and S. Dirksen. 2015. Bird movements at rotor heights measured continuously with vertical radar at a Dutch offshore wind farm. Ibis 157(3):558-566. https://doi.org/10.1111/ibi.12259

Fox, A. D., M. Desholm, J. Kahlert, T. K. Christensen, and I. Krag Petersen. 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis 148:129-144. https://doi.org/10.1111/j.1474-919X.2006.00510.x

Furness, R. W., H. M. Wade, and E. Masden. 2013. Assessing vulnerability of marine bird populations to offshore wind farms. Journal of Environmental Management 119:56-66. https://doi.org/10.1016/j.jenvman.2013.01.025

Galtbalt, B., A. Lilleyman, J. T. Coleman, C. Cheng, Z. Ma, D. I. Rogers, B. K. Woodworth, R. A. Fuller, S. T. Garnett, and M. Klaassen. 2021. Far Eastern Curlew and Whimbrel prefer flying low - wind support and good visibility appear only secondary factors in determining migratory flight altitude. Movement Ecology 9:32. https://doi.org/10.1186/s40462-021-00267-5

Garthe, S., and O. Hüppop. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. Journal of Applied Ecology 41:724-734. https://doi.org/10.1111/j.0021-8901.2004.00918.x

Gilman, P., B. Maurer, L. Feinberg, A. Durrer, and D. O'Connell. 2016. National offshore wind strategy: facilitating the development of the offshore wind industry in the United States. Technical report DOE/GO-102016-4866. Department of Energy and U.S. Department of Interior, Washington, D.C., USA.

Hijmans, R. J., E. Williams, C. Vennes, and M. R. J. Hijmans. 2021. Package "geosphere". Spherical trigonometry. Version 1.5-14. https://cran.r-project.org/web/packages/geosphere/geosphere.pdf

Hope, D. D., C. Pekarik, M. C. Drever, P. A. Smith, C. Gratto-Trevor, J. Paquet, Y. Aubry, G. Donaldson, C. Friis, K. Gurney, J. Rausch, et al. 2019. Shorebirds of conservation concern in Canada - 2019. Wader Study Group 12(2):88-100. https://doi.org/10.18194/ws.00148

Howell, J. E., A. E. McKellar, R. H. M. Espie, and C. A. Morrissey. 2020. Predictable shorebird departure patterns from a staging site can inform collision risks and mitigation of wind energy developments. Ibis 162(2):535-547. https://doi.org/10.1111/ibi.12771

Jiguet, F., P. Schwemmer, P. Rousseau, and P. Bocher. 2021. GPS tracking data can document wind turbine interactions: evidence from a GPS-tagged Eurasian Curlew. Forensic Science International: Animals and Environment 1:100036. https://doi.org/10.1016/j.fsiae.2021.100036

Johnson, A. S., J. Perz, E. Nol, and N. R. Senner. 2016. Dichotomous strategies? The migration of Whimbrels breeding in the eastern Canadian sub-Arctic. Journal of Field Ornithology 87(4):371-383. https://doi.org/10.1111/jofo.12173

Johnson, D. S., J. M. London, and Kenady. 2018. NMML/crawl: an R package for fitting continuous-time correlated random walk models to animal movement data. Version 2.1.2. Zenodo. https://doi.org/10.5281/zenodo.569569

Johnson, D. S., J. M. London, M. Lea, and J. W. Durban. 2008. Continuous-time correlated random walk model for animal telemetry data. Ecology 89:1208-1215. https://doi.org/10.1890/07-1032.1

Lindström, A., T. Alerstam, A. Andersson, J. Bäckman, P. Bahlenberg, R. Bom, R. Ekblom, R. H. G. Klaassen, M. Komiluk, S. Sjöberg, and J. K. M. Weber. 2021. Extreme altitude changes between night and day during marathon flights of Great Snipes. Current Biology 31(15):3433-3439. https://doi.org/10.1016/j.cub.2021.05.047

Loring, P. H., A. K. Lenske, J. D. McLaren, M. Aikens, A. M. Anderson, Y. Aubry, E. Dalton, A. Dey, C. Friis, D. Hamilton, R. Holberton, D. Kriensky, D. Mizrahi, L. Niles, K. L. Parkins, J. Paquet, F. Sanders, A. Smith, Y. Turcotte, A. Vitz, and P. A. Smith. 2020. Tracking movements of migratory shorebirds in the U.S. Atlantic Outer Continental Shelf Region. OCS Study BOEM 2021-008. U.S. Department of the Interior, Bureau of Ocean Energy Management, Sterling, Virginia, USA.

Loss, S. R. 2016. Avian interactions with energy infrastructure in the context of other anthropogenic threats. Condor 118 (2):424-432. https://doi.org/10.1650/CONDOR-16-12.1

Loss, S. R., T. Will, and P. P. Marra. 2013. Estimates of bird collision mortality at wind facilities in the contiguous United States. Biological Conservation 168:201-209. https://doi.org/10.1016/j.biocon.2013.10.007

Lyons, J. E., B. Winn, T. Keyes, and K. S. Kalasz. 2018. Post-breeding migration and connectivity of Red Knots in the Western Atlantic. Journal of Wildlife Management 82:383-396. https://doi.org/10.1002/jwmg.21389

Marques, A. T., H. Batalha, S. Rodrigues, H. Costa, M. J. R. Pereira, C. Fonseca, M. Mascarenhas, and J. Bernardino. 2014. Understanding bird collisions at wind farms: an updated review on the causes and possible mitigation strategies. Biological Conservation 179:40-52. https://doi.org/10.1016/j.biocon.2014.08.017

Morrison, R. I. G., D. S. Mizrahi, R. K. Ross, O. H. Ottema, N. de Pracontal, and A. Narine. 2012. Dramatic declines of

Semipalmated Sandpipers on their major wintering areas in the Guianas, northern South America. Waterbirds 35(1):120-134. https://doi.org/10.1675/063.035.0112

Musial, W., D. Heimiller, P. Beiter, G. Scott, and C. Draxl. 2016. Offshore wind energy resource assessment for the United States. NREL Technical Report NREL/TP-5000-66599. National Renewable Energy Laboratory, Golden, Colorado, USA. https://doi.org/10.2172/1324533

Newton, I. 2008. The migration ecology of birds. Academic Press, London, UK.

Niemuth, N. D., J. A. Walker, J. S. Gleason, C. R. Loesch, R. E. Reynolds, S. E. Stephens, and M. A. Erickson. 2013. Influence of wind turbines on presence of Willet, Marbled Godwit, Wilson's Phalarope and Black Tern on wetlands in the Prairie Pothole region of North Dakota and South Dakota. Waterbirds 36 (3):263-276. https://doi.org/10.1675/063.036.0304

O'Connell A., C. S. Spiegel, and S. Johnston. 2011. Compendium of avian occurrence information for the continental shelf waters along the Atlantic Coast of the United States, final report (database section - shorebirds). U.S. Department of the Interior, Geological Survey, and Bureau of Ocean Energy Management Headquarters, OCS Study BOEM 2012-076. U.S. Fish and Wildlife Service, Hadley, Maryland, USA.

Pearce-Higgins, J. W., L. Stephen, A. Douse, and R. H. W. Langston. 2012. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. Journal of Applied Ecology 49(2):386-394. https://doi.org/10.1111/j.1365-2664.2012.02110.x

Pearce-Higgins, J. W., L. Stephen, R. H. W. Langston, I. P. Bainbridge, and R. Bullman. 2009. The distribution of breeding birds around upland wind farms. Journal of Applied Ecology 46 (6):1323-1331. https://doi.org/10.1111/j.1365-2664.2009.01715.x

Piersma, T., L. Zwarts, and J. H. Bruggemann. 1990. Behavioural aspects of the departure of waders before long-distance flights: flocking, vocalizations, flight paths and diurnal timing. Ardea 78:157-184.

Prater, A. J., J. H. Marchant, and J. Vuorinen. 1977. Guide to the identification and ageing of Holarctic waders. BTO Guide 17, British Trust for Ornithology, Tring, UK.

Pyle, P. 2008. Identification guide to North American birds. Part II: Anatidae to Alcidae. Slate Creek Press, Point Reyes Station, California, USA.

R Core Team. 2020. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org

Rappole, J. H., and A. R. Tipton. 1991. New harness design for attachment of radio transmitters to small passerines. Journal of Field Ornithology 62(3):335-337.

Richardson, W. J. 1979. Southeastward shorebird migration over Nova Scotia and New Brunswick in autumn: a radar study. Canadian Journal of Zoology 57(1):107-124. https://doi.org/10.1139/z79-009

Robinson Willmott, J. C., G. Forcey, and A. Kent. 2013. The relative vulnerability of migratory bird species to offshore wind energy projects on the Atlantic Outer Continental Shelf: an assessment method and database. OCS Study BOEM 2013-207. U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs, Herndon, Virginia, USA.

Sanzenbacher, P. M., S. M. Haig, and L. W. Oring. 2000. Application of a modified harness design for attachment of radio transmitters to shorebirds. Wader Study Group Bulletin 91:16-20.

Shamoun-Baranes, J., E. van Loon, H. van Gastere, J. van Belle, W. Bouten, and L. Buurma. 2006. A comparative analysis of the influence of weather on the flight height of birds. Bulletin of the American Meteorological Society 87(1):47-61. https://doi.org/10.1175/BAMS-87-1-47

Skeel, M. A., and E. P. Mallory. 2020. Whimbrel (*Numenius phaeopus*), version 1.0. In S. M. Billerman, editor. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.whimbr.01

Spiegel, C. S., A. M. Berlin, A. T. Gilbert, C. E. Gray, W. A. Montevecchi, I. J. Stenhouse, S. L. Ford, G. H. Olsen, J. L. Fiely, L. Savoy, M. W. Goodale, and C. M. Burke. 2017. Determining fine-scale use and movement patterns of diving bird species in federal waters of the Mid-Atlantic United States using satellite telemetry. OCS Study BOEM 2017-069. U. S. Department of the Interior, Bureau of Ocean Energy Management, Sterling, Virginia, USA.

Tan, K., C. Choi, H. Peng, D. S. Melville, and Z. Ma. 2018. Migration departure strategies of shorebirds at a final pre-breeding stopover site. Avian Research 9:15. https://doi.org/10.1186/s40657-018-0108-7

U.S. Shorebird Conservation Plan Partnership (USCPP). 2015. Shorebirds of conservation concern in the United States of America—2015. U.S. Fish and Wildlife Service, Washington, D. C., USA. https://www.shorebirdplan.org/wp-content/uploads/2015/01/ShorebirdsConservationConcernJan2015.pdf

Wallover, N. J., M.-C. Martin, and F. J. Sanders. 2015. Monthly abundance and seasonal spatial distribution of shorebirds in Cape Romain National Wildlife Refuge, South Carolina. Chat 79 (2):61-78.

Watts, B. D. 2010. Wind and waterbirds: establishing sustainable mortality limits within the Atlantic Flyway. Center for Conservation Biology Technical Report Series, CCBTR-10-05. College of William and Mary/Virginia Commonwealth University, Williamsburg, Virginia, USA.

Watts, B. D., E. T. Reed, and C. Turrin. 2015. Estimating sustainable mortality limits for shorebirds using the Western Atlantic Flyway. Wader Study 122(1):37-53. https://doi.org/10.18194/ws.00005

Watts, B. D., F. M. Smith, D. J. Hamilton, T. Keyes, J. Paquet, L. Pirie-Dominix, J. Rausch, B. R. Truitt, B. Winn, and P. Woodward. 2019. Seasonal variation in mortality rates for Whimbrels (*Numenius phaeopus*) using the Western Atlantic Flyway. Condor. 121(1):1-13. https://doi.org/10.1093/condor/duy001

Watts, B. D., F. M. Smith, C. Hines, L. Duval, D. J. Hamilton, T. Keyes, J. Paquet, L. Pirie-Dominix, J. Rausch, B. Truitt, B. Winn, and P. Woodard. 2021a. The annual cycle for Whimbrel populations using the Western Atlantic Flyway. PLoS ONE 16 (12):e0260339. https://doi.org/10.1371/journal.pone.0260339

Watts, B. D., F. M. Smith, C. Hines, L. Duval, D. J. Hamilton, T. Keyes, J. Paquet, L. Pirie-Dominix, J. Rausch, B. Truitt, B. Winn, and P. Woodard. 2021b. Whimbrel populations differ in trans-Atlantic pathways and cyclone encounters. Scientific Reports 11:12919. https://doi.org/10.1038/s41598-021-92429-z

Watts, B. D., F. M. Smith, and B. R. Truitt. 2017. Departure patterns of Whimbrels using a terminal spring staging area. Wader Study 124(2):141-146. https://doi.org/10.18194/ws.00075

Watts, B. D., and B. R. Truitt. 2001. Abundance of shorebirds along the Virginia barrier islands during spring migration. Raven 71:33-39.

Watts, B. D., and B. R. Truitt. 2011. Decline of Whimbrels within a mid-Atlantic staging area (1994–2009). Waterbirds 34 (3):347-351. https://doi.org/10.1675/063.034.0308

Watts, B. D., and B. R. Truitt. 2014. Spring migration of Red Knots along the Virginia Barrier Islands. Journal of Wildlife Management 79:288-295. https://doi.org/10.1002/jwmg.828

Watts, B. D., B. R. Truitt, F. M. Smith, E. K. Mojica, B. J. Paxton, A. L. Wilke, and A. E. Duerr. 2008. Whimbrel tracked with satellite transmitter on migratory flight across North America. Wader Study Group Bulletin 115(2):119-121.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59(4):794-800. https://doi.org/10.2307/3801959

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