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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 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-northeast axis. A considerable number (42.9%) of tracks intersected with one of the two wind leases. The juxtaposition to the staging site placed wind leases within both the departure and arrival trajectories. Several species of shorebirds including hundreds of thousands of individuals make trans-Atlantic flights from three major staging sites including Delaware Bay, the lower Delmarva 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 lease placement.
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Running head: Whimbrel offshore wind

EXPOSURE OF WHIMBRELS TO OFFSHORE WIND LEASES DURING DEPARTURE FROM AND ARRIVAL TO A MAJOR MID-ATLANTIC STAGING SITE

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1 September, 2021

Soteris Kalogirou, Editor-in-Chief
Renewable Energy
Cyprus University of Technology

Dr. Kalogirou,

Attached please find a manuscript entitled "**Exposure of whimbrels to offshore wind leases during departure from and arrival to a major mid-Atlantic staging site**" that we would like to be considered for publication in Renewable Energy.

This study and publication were completed with logistical support and/or funding provided by the US Fish and Wildlife Service, the National Fish and Wildlife Foundation's Atlantic Flyway Shorebird Initiative, The Nature Conservancy, The Georgia Department of Natural Resources Non-game Section and the Virginia Coastal Zone Management Program at the Department of Environmental Quality.

We used satellite transmitters to track whimbrels departing from and arriving to a coastal staging site to determine their trajectory on trans-Atlantic flights relative to two offshore wind leases. More than 40% of whimbrel flights intersected with wind leases. Active wind leases have similar juxtaposition to two other major shorebird staging sites along the south Atlantic Coast.

We believe that this information is of interest to the readership of Renewable Energy. The authors have no conflict of interest to report and this information has not appeared or been submitted elsewhere.

If you require additional information, please let me know.

Sincerely,

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Ethics statement

All birds were captured and handled under the Institutional Animal Care and Use Committee protocol IACUC-2017-04-18-12065 of The College of William and Mary, Environment Canada Animal Care Committee protocols EC-PN-12-006, EC-PN-13-006, EC-PN-14-006, Mount Allison University Animal Care Committee protocol 15-14, and the Government of the Northwest Territories Wildlife Care Committee protocol NWTWCC2014-007.

- The United States is pursuing a diversified energy portfolio that includes offshore wind
- Offshore wind energy leases may threaten birds making trans-Atlantic migratory flights
- We used satellite transmitters to track whimbrels making trans-Atlantic flights
- > 40% of flights intersected leases off the coast of Virginia and North Carolina
- More study is needed to inform placement and operation of offshore wind leases

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 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-northeast axis. A considerable number (42.9%) of tracks intersected with one of the two wind leases. The juxtaposition to the staging site placed wind leases within both the departure and arrival trajectories. Several species of shorebirds including hundreds of thousands of individuals make trans-Atlantic flights from three major staging sites including Delaware Bay, the lower Delmarva 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 lease placement.

Key Words — Whimbrel, Numenius phaeopus, satellite tracking, offshore wind, outer continental shelf, Western Atlantic Flyway.

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 energy that may be produced domestically. Offshore wind represents a significant component of this renewable energy strategy. The Atlantic Coast offers abundant wind resources, shallow, near-shore waters in close proximity to large load centers with some of the most lucrative and rapidly expanding energy markets in the country (Gilman et al. 2016). Near-shore waters 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 km^2 of the Atlantic OCS is under lease with an additional 11,235 km^2 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 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 supporting hundreds of millions of individuals annually including 164 species of waterbirds, 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). Due to their low reproductive potential, many shorebirds are vulnerable to increased adult mortality (Watts et al. 2015).

Whimbrels (*Numenius phaeopus*) are large shorebirds that use the WAF during both spring and fall migration (Skeel and Mallory 2020, Johnson et al. 2016). 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 (Donaldson et al. 2000, Brown et al. 2001).

The construction of any structure within the airspace represents a potential hazard to birds (Erickson et al. 2005). At the population level, probability of impact from a specific hazard is determined by two independent factors including vulnerability and exposure. Population vulnerability is the susceptibility of a population to perturbations in vital demographic rates or in the case of hazards the ability of a population to absorb hazard-related mortality. Population exposure to a hazard is the extent to which the population is expected to interact with and be impacted by the hazard. In the case of wind turbines, this includes the extent to which the population spatially overlaps with the hazard and the conditional probability that if it overlaps with the hazard that it will be impacted by the hazard. If a population has no spatial overlap with the hazard, then the likelihood of impact is expected to be zero. One of the most effective means of minimizing the impacts of hazards on bird populations is to locate structures away from major activity centers.

Because the greatest volume of the 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 occur along the Atlantic Coast including Delaware Bay (Clark et al. 1993), the Delmarva Peninsula (Watts and Truitt 2001, 2011, 2014) and the Georgia Bite (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. 2012, Loring et al. 2020, Watts et al. 2021). 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 to 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. The lower Delmarva supports thousands to tens of thousands of whimbrels during both the spring and fall migration periods. Whimbrels stage within the site for approximately 4 weeks before initiating the next leg of migration (Watts et al., unpublished). In addition to whimbrels, the staging area 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 (http://www.unesco.org), a Western Hemisphere Shorebird Reserve Site with international status (http://www.whsrn.org), is the site of a National Science Foundation Long-term Ecological Research site (http://amazon.evsc.virginia.edu) and the focus of a multi-organizational partnership dedicated to bird conservation.

The two BOEM leases include a site offshore of Virginia Beach, VA (centered on 36°905′ N, 75°365′ W) and a site offshore of Kitty Hawk, NC (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). We selected these birds for inclusion in this study because they staged on the lower Delmarva Peninsula during autumn and/or spring. All birds were aged as adults by plumage (Prater et al. 1977, Pyle 2008) and were banded with 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 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 ($\bar{x} = 563.9 \pm 20.6$) 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 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 ($\bar{x} = 5.48 \pm 0.07$) 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 using departure and arrival dates from and to the lower Delmarva staging site respectively. We used tracking data to determine the dates of departure and arrival. We consider departure or the onset of migration to be when birds made decisive movements away from the site. In order to identify these breakout movements, we used staging locations to develop centroids and consider the first departure movement to be the first location that exceeded 2 standard deviation units beyond the mean of movements around centroids. We consider the dates of breakout movements to be the dates of departure. We consider arrival to be the dates of first locations within the site. In cases where 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 SD below the mean whimbrel flight speed ($\bar{x} = 14.7 \pm 0.3$ m/s, n = 45; Watts et al. 2021), we interpolated arrival and departure times using the mean whimbrel flight speed and great circle distance between the two points. Departure and arrival were both abrupt and we recorded no "false starts or ends" to migratory movements.

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 (Duoung 2007) in program R (R Core Team 2020). We used the normal (or Gaussian) kernel and a smooth cross-validation bandwidth selector (Duoung 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. 2017) 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. Due to 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 and London 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 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 individual and population-level exposure of whimbrels to BOEM wind leases 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 used an estimate of the mean trajectory of birds leaving from and arriving to the staging site to project population-level overflight of the wind leases. We projected mean flight lines (±SE) from stopover centroids. We overlaid flight lines on polygons of wind leases and estimated the proportion (estimated % of population) of birds that would overfly the polygons based on the level of overlap.

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 Rayleigh's Uniformity Test (Berens 2009). We compared orientation of autumn departure and spring arrival using Welches 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 (Figure 1). Birds departed the staging site in autumn moving along a southeast bearing (Figure 2a) and exhibited significant directionality (mean bearing =144±7.9°, r-bar = 0.88, $p < 0.001$). Birds arrived on the staging site moving along a northwest bearing (Figure 2b) and also exhibited significant directionality (mean bearing =342±10.9° - back azimuth = 162±10.9°, r-bar = 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 are in surprising agreement with these bearings (Table 1). Distances between departure/arrival centroids and centroids of wind leases ranged from 66 to 131 km (Table 1).

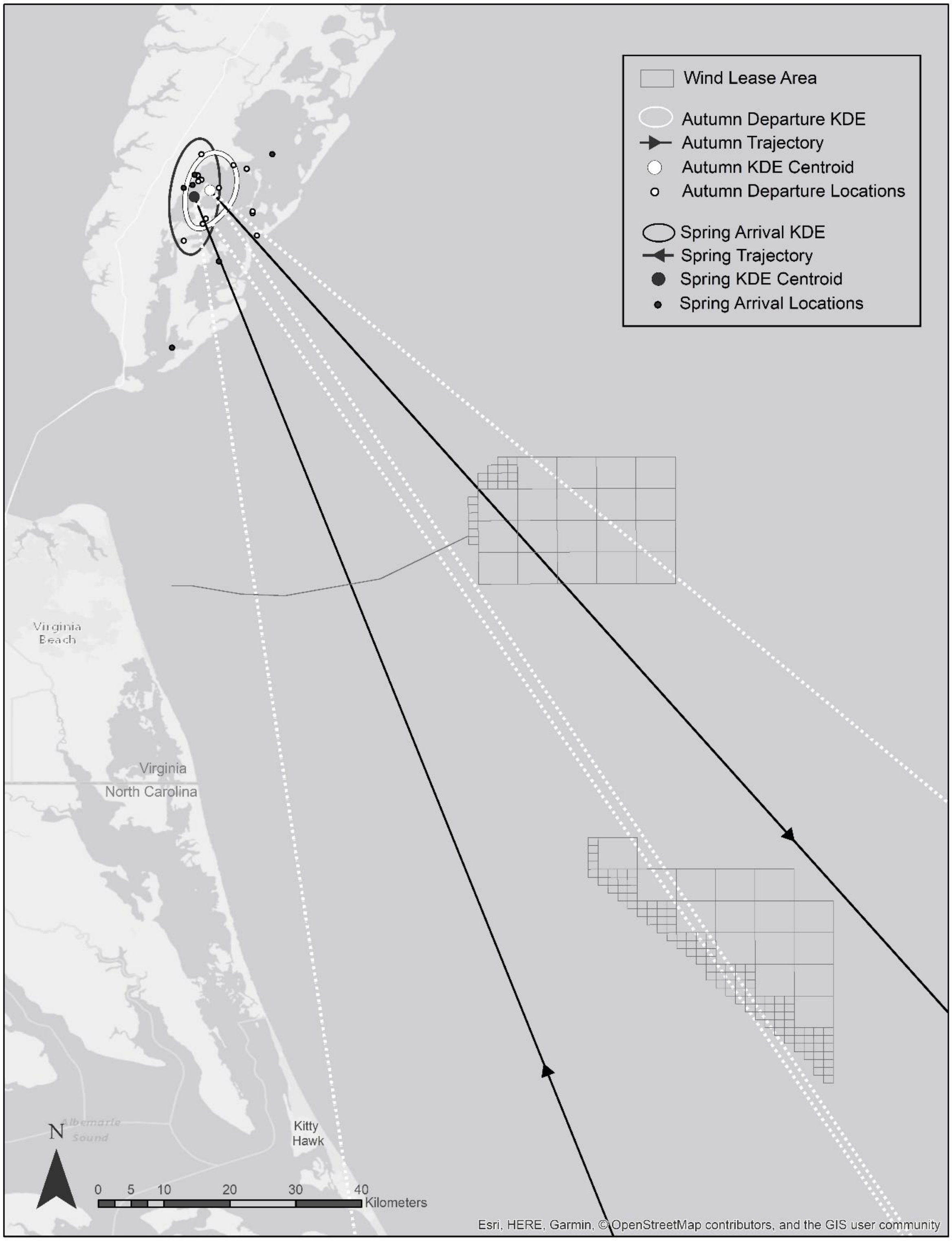

Figure 1. Boundary maps of Virginia and North Carolina wind leases and autumn departure and spring arrival KDEs. Track trajectories depict mean ± SE of autumn departure and spring arrival bearings. Tracks were recorded for birds fitted with solar-powered satellite transmitters. This figure was produced in ArcGIS 10.7.1 by an author: https://www.esri.com/

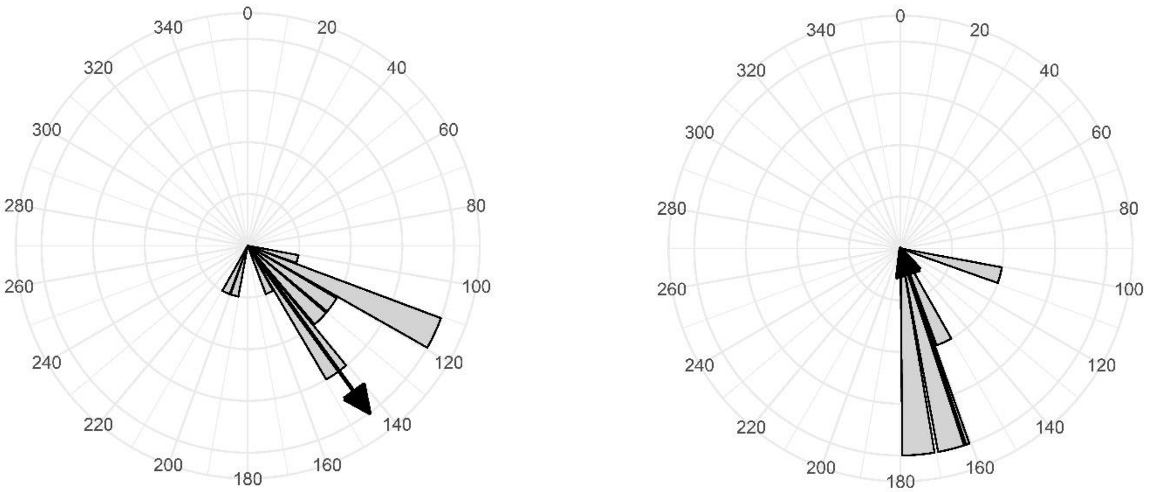

Figure 2a

Figure 2b

Figure 2. Frequency distribution of orientation (bearings) of whimbrels tracked departing in the autumn from (2a) and arriving in the spring to (2b) the lower Delmarva staging site. Bearings in the spring represent the back-azimuth of travel to better relate the orientation relative to wind leases.

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

Table 1. Juxtaposition between centroids of autumn departure and spring arrival locations and the centroids of wind leases off the coast of Virginia and North Carolina. Autumn departure and spring arrival reflect locations for whimbrels tracked with satellite transmitters that staged along the lower Delmarva Peninsula in Virginia.

We documented whimbrel tracks that intersected with wind leases. Tracked whimbrels crossed the Atlantic OCS 21 times including 15 in the autumn and 6 in the spring. Nine (42.9%) of these tracks over flew wind leases including 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 over flew lease) may have higher exposure to the Virginia wind lease compared to whimbrels arriving (0 of 6 over flew the lease) in the spring (G-statistic = 2.12, df = 1, p = 0.07). This may be expected based on the more northerly trajectory in the autumn relative to the position of the two leases. 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 (mean = 24 August ± 4 days SE) during autumn migration. Birds arrived on site from 5 April through 6 May (mean = 17 April ± 5 days).

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 or arrival flights of shorebirds using major staging sites (e.g., Richardson 1979, Piersma et al. 1990, Battley et al. 2012, Tan et al. 2018). Flight orientation at departure is generally consistent with what would be expected based on the destination with some adjustment for wind direction. 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. 2021). A generalized southeast orientation for shorebirds that leave the Atlantic Coast in fall to make transoceanic flights to winter grounds 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. 2012, 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 may have exposure to turbines constructed within the leases. Due to 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.

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 due to weight constraints so we do not know if birds crossed wind leases within the rotor swept zone (RSZ, 25-250 m). No information is available on the migration altitudes of whimbrel and how these altitudes may vary with conditions or time of day. 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. 2016) 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, Lindstrom 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. The other two major shorebird staging sites along the south Atlantic Coast including 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 (*C. pusilla*) and short-billed dowitcher (*Limnodromus griseus*). These species likely take similar trajectories as 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 around 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.

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Data Availability Statement: Our data is deposited within Movebank, a free online animal tracking database hosted by Max Planck Institute for Ornithology at https://www.movebank.org/

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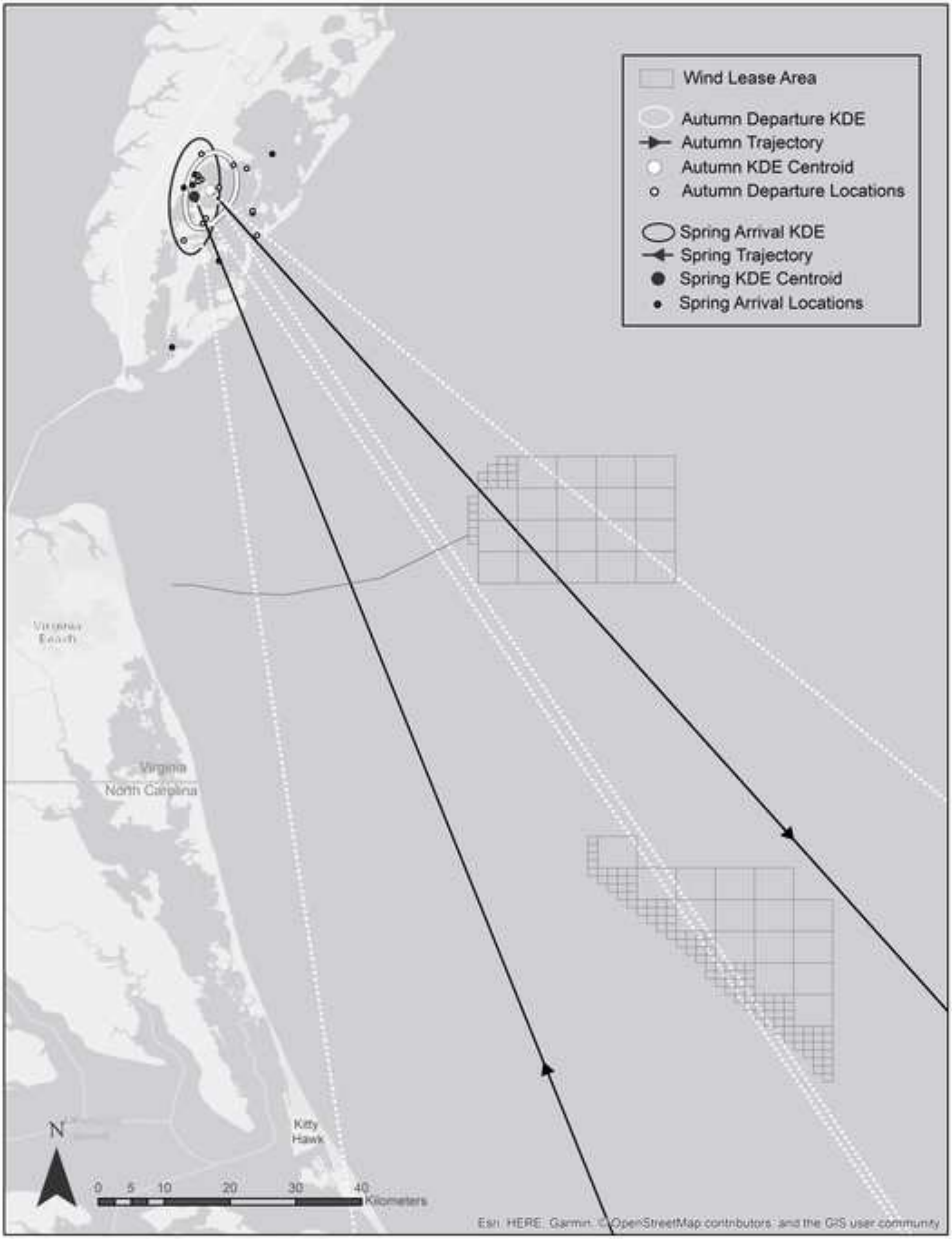
Figure 1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Autumn KDE Centroid
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Spring Trajectory
Spring KDE Centroid
Spring Arrival Locations
Virginia
North Carolina
Kitty Hawk
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Figure 2

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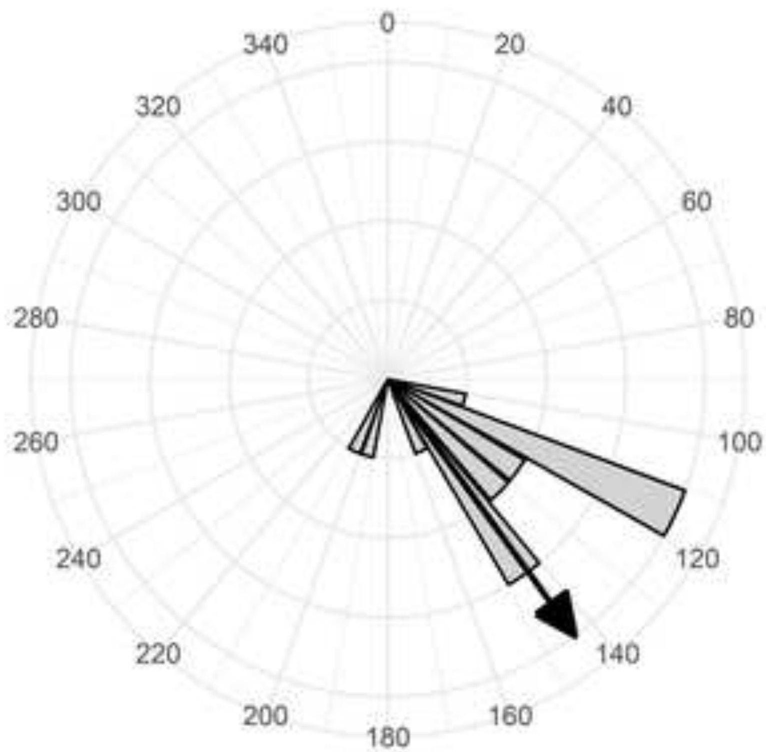

Figure 2a

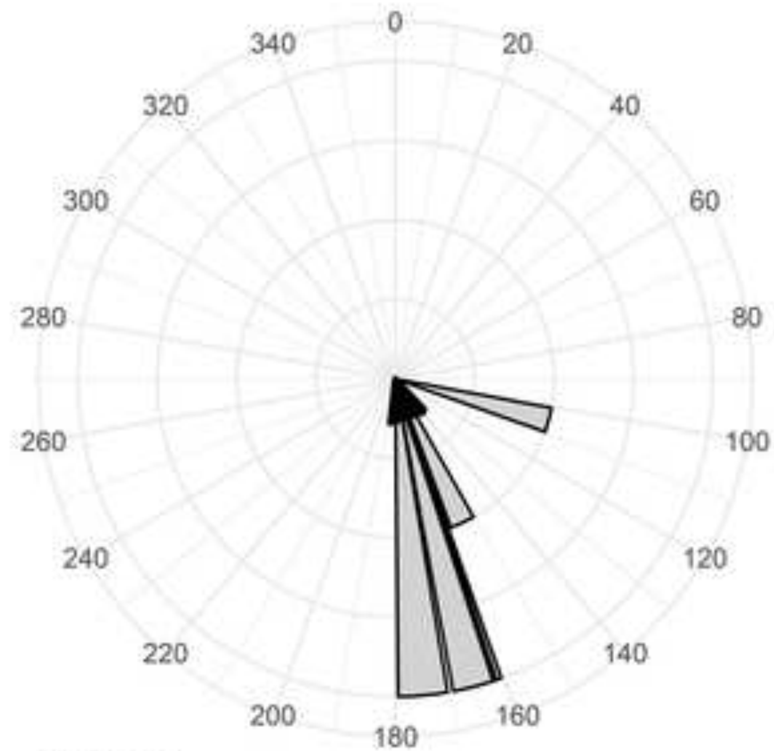

Figure 2b

Credit Author Statement

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

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: