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The first tracking data for juvenile Hudsonian Whimbrel

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There is evidence of a decline in the Whimbrel population on the West Atlantic Flyway. As efforts continue to identify the causes of decline, juvenile migration ecology and survival has been identified as a key information gap. In 2015, we launched a study to address this on a flyway scale. We deployed satellite and GPS transmitters on juvenile Whimbrel captured on Cape Cod, Massachusetts, USA, a southbound staging area used by both juvenile and adult Whimbrel. Using the transmitter data, we established migratory connectivity between Cape Cod and other sites along juvenile Whimbrel migration routes. We documented Whimbrel movement patterns during migration and on their non-breeding grounds, including non-breeding home ranges and a delayed maturation period of up to 2.5 years. We also identified nocturnal roosts on Cape Cod, which researchers can use for long-term monitoring of adult and juvenile birds. The current study has laid the groundwork for launching a full-scale, follow-on study of juveniles at this site. This could collect demographic data, such as survival and recruitment, which will contribute to a demographic model that will help identify priorities for conservation action on a hemispheric scale.

Keywords

migration ecology

shorebird conservation

Numenius hudsonicus

INTRODUCTION

The population of Hudsonian Whimbrel *Numenius hudsonicus* (hereafter Whimbrel) in the West Atlantic Flyway is declining significantly. Evidence for this decline spans several decades and has been documented from the breeding grounds (Ballantyne & Nol 2015), at stopover areas (Bart *et al.* 2007, Watts & Truitt 2011, Smith *et al.* 2023), and on the non-breeding grounds (Morrison *et al.* 2012). The West Atlantic Flyway population of Whimbrel has experienced an estimated 4% annual decline at an Atlantic coast staging area between the 1990s and 2000s (Watts & Truitt 2011), leading to their status as a United States Fish and Wildlife Service (USFWS) Bird of Conservation Concern and a Species of Greatest Conservation Need in most coastal states in the USFWS Northeast Region. There are still critical gaps in our understanding of Whimbrel ecology and threats to populations. Addressing these gaps through research should lead to improved conservation and management recommendations.

Little is known about juvenile Whimbrel in the Western Hemisphere. Work on the breeding grounds in Hudson Bay has provided data on nesting productivity (Ballantyne & Nol 2015, Weiser *et al.* 2018) and the rate of chick returns to natal areas (Skeel 1983). As with most shorebirds, migration timing differs between adults and juveniles. For Eurasian Whimbrel *Numenius phaeopus*, this has been documented through photo analysis of public observations (Hines *et al.* 2023) and a tracking study in Iceland (Carneiro *et al.* 2024). There is still a lack of information on juvenile survival rates and maturation periods on the non-breeding grounds. Survival rates during these first years of life are largely inferred from studies on related species, which suggest that juveniles experience higher levels of mortality than adults (Bainbridge & Minton 1978, Kus *et al.* 1984, Sandercock 2003, Tavera *et al.* 2020). To begin to address these information gaps, there is a need to identify specific locations with high, predictable densities of juvenile Whimbrel so that researchers can launch studies to investigate movement ecology, survival, and recruitment – factors that can directly influence a population's decline or recovery (Sæther & Bakke 2000, Schulte *et al.* 2010, Wilson & Martin 2012).

The presence of Whimbrel on Cape Cod in Massachusetts, USA, during southbound migration is well documented (Mackay 1892, Veit & Petersen 1993), while northbound records are currently rare and

irregular. In recent decades, rigorous monitoring efforts in the state have been sporadic, but eBird records (eBird 2024) confirm the presence of Whimbrel from July through early October. International Shorebird Survey (ISS) data confirm a high count of 701 Whimbrel at a nocturnal roost at Monomoy National Wildlife Refuge (NWR) in July 1999 (ISS 2024). Records containing photo vouchers show that most birds present during July and August are adults and most birds present in September are juveniles (Hines *et al.* 2023). However, the number of juveniles present and their migration ecology remain poorly known.

In 2015, we launched a Whimbrel study on Cape Cod with the goals of (1) filling information gaps on juvenile Whimbrel migration ecology; (2) establishing migratory connectivity between Cape Cod and other sites along juvenile Whimbrel migration routes and (3) establishing a long-term monitoring protocol for juvenile Whimbrel on Cape Cod.

METHODS

Site description

We targeted Cape Cod, Massachusetts for transmitter deployment due to its role as a southbound staging area for juvenile Whimbrel. We reviewed eBird records to determine the locations on Cape Cod with the highest numbers of Whimbrel during southbound migration. These locations were on the outer portion of Cape Cod, concentrated in salt marshes around Wellfleet Harbor and the south coast of Chatham (Fig. 1). Capture locations consisted of diurnal foraging sites and high tide roosts (Table 1). Foraging habitat included salt marshes with exposed peat banks along tidal creeks. Diurnal high tide roosts consisted of sandy beaches or supratidal sand ridges embedded within salt marshes.

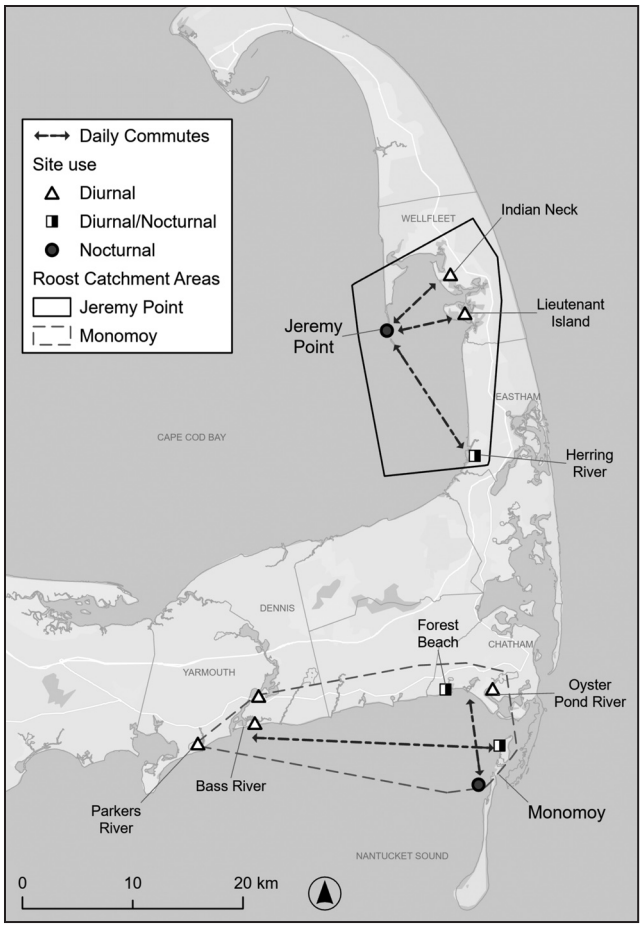

Fig. 1. Generalized nocturnal, diurnal, and mixed-use sites for Whimbrel while staging on Cape Cod, Massachusetts, USA (see Fig. 2 for locus). Catchment areas encompass all the points associated with the nocturnal roost. Arrows show generalized daily commutes between diurnal and nocturnal sites.

Light Gray Canvas base map: Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS (2024); Municipal Boundaries layer: Massachusetts Highway Survey Section, MassGIS (2023).

Table 1. Transmitter deployment information for juvenile Whimbrel captured on Cape Cod, Massachusetts, USA, 2015–2022. Transmitters were 5-g Platform Transmitter Terminal (PTT) manufactured by Microwave Telemetry and one 9-g Ornitrack GPS transmitter manufactured by Ornitela. Transmitter duration extends from deployment to the final transmission.

Tag ID	Transmitter	Deployment Date	Capture Location (Massachusetts, USA)	Coordinates	Transmitter Duration (days)
136618	PTT	7 Sept 2015	Forest Beach, Chatham	41.6733°N, 70.0197°W	643
136617	PTT	21 Sept 2016	Lieutenant Island, Wellfleet	41.8944°N, 70.0052°W	2
136620	PTT	21 Sept 2016	Lieutenant Island, Wellfleet	41.8944°N, 70.0052°W	98
136619	PTT	11 Sept 2017	Lieutenant Island, Wellfleet	41.8944°N, 70.0052°W	938
176014	PTT	10 Sept 2019	Lieutenant Island, Wellfleet	41.8944°N, 70.0052°W	16
176015	PTT	24 Sept 2020	Herring River, Eastham	41.8149°N, 70.0015°W	28
176013	PTT	14 Sept 2021	Fox Island, Wellfleet	41.9061°N, 70.0148°W	308
215648	Ornitrack	18 Sept 2022	Bass River, West Dennis	41.6679°N. 70.1756°W	5

We identified Cape Cod nocturnal roosts (Fig. 1) for long-term monitoring using previous ISS records, new tracking data collected during this study, and field confirmation. Sites within Monomoy National Wildlife Refuge are previously known Whimbrel roosts, first observed in the 1970s. Key sites are North Monomoy Island, Minomoy Island and Jeremy's Point (Fig 1). North Monomoy Island (41.63829°N, 69.97872°W) is an 86-ha. salt marsh island that is 1.1 km from the mainland with supratidal ridges in the interior that function as roost sites. Minimoy Island (41.61504°N, 69.99582°W) is a 7.5-ha. salt marsh island with supratidal sand ridges that is 1.5 km southwest of North Monomoy Island. We first discovered the roost at Jeremy Point in Wellfleet, Massachusetts (41.88463°N, 70.07047°W) through tracking data from this project. Jeremy Point is a largely unvegetated sandspit approximately 1.5 km long and reaching a minimum width of 0.2 km at high tide.

Capture and transmitter deployment

We obtained state and federal permits to capture birds, as well as research permits from land managers at anticipated trap locations. We captured birds using noose lines, an adaptation of a noose carpet that is less visible and more suitable to peat banks in salt marshes. We aged all birds by the presence of retained juvenile feathers (Pyle 2008) and banded them with US Geological Survey aluminum bands and coded leg flags on the upper leg. We could not determine the sex of the birds.

We fitted birds with a 5-gram Platform Transmitter Terminal (PTT) manufactured by Microwave Telemetry (Columbia, MD, USA; $n = 7$) or an Ornitrack 9-gram GPS transmitter manufactured by Ornitela (Vilnius, Lithuania; $n = 1$) using a leg-loop harness secured by Teflon ribbon fastened with crimps. This method aligns with multiple Whimbrel tracking studies (e.g., Watts *et al.* 2019). The transmitter package was below 3% body mass for all individuals tracked in this study, with a mean body mass of 528 g ± 21.92 (SE). We did not exclude any birds from our analysis.

Tracking data

The PTTs located birds 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, Largo, MA, USA; Fancy *et al.* 1988). We programmed the transmitters to operate with a duty cycle of 25 hours off and 5 hours on. The Advanced Research and Global Observation Satellite system (www.argos-system.org) estimated locations using a Doppler shift in signal frequency and calculated 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) of 3 (≤ 150 m), 2 (150–350 m), 1 (350–1,000 m), 0 (> 1,000 m), A (location based on three messages; no accuracy estimate), B (location based on two messages; no accuracy estimate), or Z (location process failed; CLS 2011). We used points with LC 1–3 to map Whimbrel locations. Timestamps for points with LC 1–3, 0, A, and B were used to determine date and time attributes.

The Ornitrack transmitter recorded GPS coordinates, flight altitude, speed, direction, horizontal dilution of precision (a measure of how well distributed satellites are, which can impact the accuracy of horizontal positioning), and battery voltage at intervals of 30 min with an accuracy of < 25 m. Tracking data were uploaded via the GSM/GPRS/3G telecommunication networks and downloaded from Ornitela's website (https://www.ornitela.com/).

Application of transmitter data

We used tracking data to assess juvenile Whimbrel migratory and local movements at staging areas, stopover sites, and non-breeding grounds. ArcPro 3.1.0 (ESRI) was used for all mapping and measurements. R software (version 4.3.1, R Core Team 2015) was used to estimate nocturnal roost catchment areas and home ranges.

Migratory movements – We identified stopovers, staging areas, and non-breeding grounds for each bird. We classified stopovers as sites used during migration for relatively short periods of time, less than one week ($n = 4$; minimum length of stay (MLOS; time between first and last transmission at a site), 2–27 hrs; Warnock 2010). Our ability to identify stopovers using only the tracking data was limited by the duty cycle and location accuracy of the PTTs. We manually assessed clusters of points on or near land (within the location accuracy for each point) along migration routes. We calculated the distance and flight speed between consecutive points, and if birds transmitted at a location for longer than it would take to fly over using mean Whimbrel flight speed (14.8 m/s; Watts *et al.* 2021a) we deemed it a potential stopover. We classified staging areas as sites used during migration for 1–6 weeks ($n = 5$, MLOS 15–21 days; Warnock 2010). Non-breeding grounds were defined as southern destinations used for extended periods (months to years; $n = 4$, MLOS 63–923 days).

We calculated centroids for each site using the Mean Center tool in ArcGIS Pro (Esri, CA, USA). We mapped migration routes and calculated minimum distances (great elliptic) between the centroids of sites and travel points. We determined the arrival date, departure date, and MLOS for each site, as well as the travel duration between sites. To determine departure and arrival dates that occurred outside of the duty cycle, we interpolated the date using the distance between the nearest travel point and site point and the mean Whimbrel flight speed (14.8 m/s, Watts *et al.* 2021a).

Local movements – To assess the birds' daily movements at staging and non-breeding sites, we separated tracking points into diurnal or nocturnal locations based on local

sunrise and sunset schedules. Points were considered nocturnal if they transmitted between two hours after sunset and two hours before sunrise, or diurnal if they transmitted between two hours after sunrise and two hours before sunset. The four-hour windows centered around sunrise and sunset were excluded to account for the periods when Whimbrel were most likely to make their daily commutes based on previous observations and literature (Sanders *et al.* 2021). We created maps of the points overlaid onto aerial imagery (Esri World Imagery 2024) and visually assessed the maps for patterns in diurnal or nocturnal activity.

We only detected temporal patterns in the Whimbrel movements on Cape Cod, where there was a separation of diurnal and nocturnal activity for some sites. We calculated centroids for each cluster of points and classified each site as diurnal, nocturnal, or used during both day and night. We conducted field observations at the identified sites to confirm Whimbrel presence and site use (e.g., diurnal vs. nocturnal; roosting vs. foraging). We defined nocturnal roosts as sites used consistently by groups of juvenile Whimbrel to roost at night. We delineated the catchment areas of each nocturnal roost using Minimum Convex Polygons in R package 'adehabitatHR' (Calenge 2023). Catchment areas include all the points associated with a particular nocturnal roost, such as those that reflect diurnal activity or occasional nocturnal use.

We estimated the distance of one-way commutes between diurnal and nocturnal sites for each bird. We identified commutes as consecutive points, one at a diurnal site and the other at a nocturnal site, within the same duty cycle. The PTTs were only able to capture a limited number of one-way commutes per bird (n = 0–3) because of the duty cycle, whereas the Ornitrack documented all commutes for the one bird fitted with this transmitter (n = 9). We calculated minimum distances between commute points to obtain the one-way commute distances. If more than one commute was documented for a bird, we reported the mean commute distance. If diurnal and nocturnal sites overlapped, the commute distance was zero.

We estimated non-breeding home ranges using autocorrelated kernel density estimation (AKDE) methods (Fleming 2015). We followed the guidelines provided by Silva *et al.* (2021) to format data, check for range residency, select movement models using corrected Akaike's information criterion (AICc), and calculate home range (95% utilization distributions, UD) and core area (50% UD) estimates. We performed this analysis using the 'ctmm' R package (Calabrese *et al.* 2016). We used the model selected via the ctmm.select function, Ornstein-Uhlenbeck (OU) anisotropic, with perturbative Hybrid Residual Maximum Likelihood (pHREML) and weighted area-corrected AKDE (wAKDEc) to account for small sample sizes and irregular temporal sampling. We excluded isolated flights outside of the birds' primary non-breeding areas from the home range estimate calculations.

Nocturnal roost monitoring on Cape Cod

Throughout the study, we performed on-the-ground Whimbrel surveys at nocturnal roosts and diurnal sites identified through tracking data on Cape Cod. In 2022 and 2023, we performed a single juvenile Whimbrel count at nocturnal roosts located at Jeremy Point and North Monomoy Island. These counts were performed in the evening, approximately two hours prior to civil twilight until visibility was lost, from locations that had direct views of either flight lines towards the roost sites or birds landing at the roost site. Birds were carefully counted by surveyors positioned on a boat or land using spotting scopes and binoculars. As the Whimbrel arrived close to the observers, they could be aged using uniformly juvenile scapular and covert feathers.

RESULTS

Cape Cod

We captured eight juvenile Whimbrel from 2015–2022 at Lieutenant Island (n = 5), Forest Beach (n = 1), Herring River marshes (n = 1), and the Bass River marshes (n = 1; Table 1, Fig. 1). The MLOS on Cape Cod was between 2–19 days (mean = 10 ± 2.1 days SE). The tracking data documented seven birds commuting between diurnal sites and nocturnal roosts for at least part of their stays. The remaining bird (Tag ID: 136620) used two separate nocturnal sites and one diurnal site, but the tracking data did not document any commutes between the sites.

We identified five nocturnal sites through the tracking data (Table 2, Fig. 1), though three of these sites were occasionally used during the day. Only two nocturnal sites were used by more than one tagged bird: Jeremy Point (n = 5) and North Monomoy Island (n = 3). These two sites were field-confirmed to be consistently used, communal nocturnal roosts for juvenile Whimbrel and were selected for long-term monitoring. Three birds (Tag IDs: 136618, 176015, and 136620) used multiple nocturnal sites while staging on Cape Cod.

Whimbrel documented using the Jeremy Point nocturnal roost spent the diurnal hours in salt marshes around Wellfleet Harbor (n = 4), specifically around Indian Neck and Lieutenant Island, and the Herring River marshes in Eastham (n = 1; Table 2, Fig. 1). Birds using the Monomoy nocturnal roosts spent diurnal hours on North Monomoy (n = 1), in Chatham marshes associated with Forest Beach and Oyster Pond River (n = 1), the Bass River marshes in West Dennis (n = 1), and the Parkers River marshes in Yarmouth (n = 1; Table 2, Fig. 1). Juvenile Whimbrel staging on Cape Cod commuted 5.1–20.4 km (mean = 12.5 ± 1.3 km SE; Table 2, Fig. 1) each way between nocturnal and diurnal areas. The average commutes for Jeremy Point and Chatham birds were 7.3 ± 1.2 km (SE) and 15 ± 1.4 km (SE), respectively.

Table 2. Nocturnal and diurnal sites and estimated daily commutes for juvenile Whimbrel tracked on Cape Cod, Massachusetts, 2015–2022. For birds with only one documented commute, we report the actual commute distance. For birds with multiple documented commutes, we report the average commute distance. 'Number of commutes' refers to the number of one-way commutes captured in the tracking data. Sites are mapped in Fig. 1.

Tag ID	Nocturnal Sites	Diurnal Sites	Number of commutes	Commute distance (km; ± SE)
136618	Minimoy and North Monomoy, Chatham	Forest Beach and Oyster Pond River, Chatham	3	7.3 ± 0.4
136617	Jeremy Point, Wellfleet	Lieutenant Island, Wellfleet	1	5.7
136620	Forest Beach and North Monomoy, Chatham	North Monomoy, Chatham	0	-
136619	Jeremy Point, Wellfleet	Lieutenant Island, Wellfleet	2	5.8 ± 0.7
176014	Jeremy Point, Wellfleet	Lieutenant Island and Indian Neck, Wellfleet	1	5.1
176015	Jeremy Point, Wellfleet Herring River, Eastham	Herring River, Eastham	1	12.8
176013	Jeremy Point, Wellfleet	Wellfleet Harbor, Wellfleet	1	8.7
215648	North Monomoy, Chatham	Parkers River, Yarmouth Bass River, West Dennis	9	17.6 ± 0.4

Table 3. Results of juvenile Whimbrel counts at nocturnal roosts on Cape Cod, Massachusetts, USA in 2022 and 2023. Counts were conducted at Jeremy Point in Wellfleet and on North Monomoy Island, located within Monomoy NWR in Chatham. One count was conducted per site in September of each year as part of a newly established long-term monitoring program. No adults were observed during these surveys.

Date	Roost	Count
17 Sept 2022	Jeremy Point	51
20 Sept 2022	North Monomoy Island	43
	Total 2022:	**94**
6 Sept 2023	Jeremy Point	55
7 Sept 2023	North Monomoy Island	14
	Total 2023:	**69**

During nocturnal roost surveys in 2022 and 2023 at the Jeremy Point and North Monomoy roosts, the total numbers of juvenile Whimbrel counted were 94 and 69, respectively (Table 3). No adults were observed during these counts.

Southbound migration

Of the eight tagged juveniles, three stopped transmitting while on Cape Cod after 2–16 days of transmission (Tag IDs: 136617, 176014, and 215648; Table 1). The other five departed Cape Cod between 19 September and 5 October (mean = 27 Sep ± 3.1 days SE; Table 4) of their capture years. These birds flew nonstop across the Atlantic Ocean to the Caribbean or South America (Fig. 2). The duration of their southbound flights ranged from 2.5–4 days (mean = 3.1 ± 0.3 days SE) with a mean minimum distance of 3,466 ± 215 km SE (range 2,619–3,787 km; Table 4).

These five birds first made landfall after their southbound transatlantic flights between 22 September and 9 October (mean = 30 Sep ± 3.5 days SE) in the British Virgin Islands (n = 1) or Venezuela (n = 4; Table 4). Two birds stayed at these sites throughout the non-breeding season (Tag IDs: 136618 and 136619). Whimbrel 136620 had a brief stopover in Delta Amacuro (9.558173°N, 61.041323°W), Venezuela (MLOS 4 hrs) before reaching its non-breeding site in Guyana. Two birds staged at Laguna Juncal near the José Antonio Anzoátegui Petrochemical Complex in Anzoátegui, Venezuela (10.07418°N, 64.80621°W) after their transatlantic flights: Whimbrel 176013 (MLOS 22 days; Sep–Oct 2021) and 176015 (MLOS 16 days; Oct 2020). Both birds continued east along the northern coast of South America after leaving this site. Whimbrel 176013 left the Laguna Juncal on 14 October 2021 and flew approximately 656 km southeast to Guyana (8.08793°N, 59.21625°W), with one brief stopover (MLOS 2.5 hrs) in Delta Amacuro, Venezuela. It staged in Guyana for 15 days before flying approximately 525 km southeast to its non-breeding grounds in Suriname. Whimbrel 176015 stopped transmitting on 22 Oct 2020, less than one day after leaving Laguna Juncal and flying 438 km east towards Tobago.

Table 4. The southbound migratory movements to non-breeding season sites used by juvenile Whimbrel fitted with satellite transmitters on Cape Cod, Massachusetts, USA, 2015–2021. Landfall locations are the first transmitter points on land following transatlantic flights. The coordinates for non-breeding sites reflect the centroids for all associated transmitter points. The minimum length of stay (MLOS) is the time between the first and last transmission at a site. Tag ID 176015 stopped transmitting before arriving at a non-breeding site.

		Southbound Travel				Non-breeding Site		
Tag ID	Departure Date from Cape Cod	Duration (days)	Distance (km)	Landfall Date	Landfall Location	Non-breeding Site	Arrival Date	MLOS (days)
136618	26 Sept 2015	2.5	2,619	29 Sept 2015	British Virgin Islands 18.70976°N, 64.27333°W	British Virgin Islands 18.58230°N, 64.33833°W	29 Sept 2015	549
136620	5 Oct 2016	5.1	3,787	9 Oct 2016	Venezuela 9.55654°N, 61.06179°W	Guyana 7.66297°N, 58.88577°W	10 Oct 2016	80
136619	23 Sept 2017	3.1	3,609	26 Sept 2017	Venezuela 11.66080°N, 69.94282°W	Venezuela 11.44332°N, 70.13920°W	26 Sept 2017	923
176015	2 Oct 2020	3.2	3,708	6 Oct 2020	Venezuela 10.20710°N, 65.63699°W	-	-	-
176013	19 Sept 2021	2.8	3,609	22 Sept 2021	Venezuela 10.11901°N, 64.73167°W	Suriname 5.98334°N, 54.95561°W	2 Nov 2021	236

Non-breeding grounds

Four of the eight tagged Whimbrel were known to have reached their non-breeding grounds in the British Virgin Islands, Guyana, Venezuela, and Suriname. Birds reached these destinations between 26 September and 2 November (mean = 6 Oct ± 10 days SE; Table 4, Fig. 2). Birds transmitted between 80–923 days (mean = 447 ± 186 days SE) from their sites before they either went offline (n = 3) or began their northbound migration (n = 1, Tag ID: 136618).

While on the non-breeding grounds, Whimbrel used sites for both diurnal and nocturnal activities and daily commutes between sites were not documented. Birds had estimated home ranges between 2.3–222.1 km^2 (mean = 130.3 ± 53.7 km^2) with core areas of 0.3–23.6 km^2 (mean = 13.1 ± 5.6 km^2; Fig. 3). Two birds (Tag IDs: 136619 and 136620) remained within their home ranges throughout the non-breeding season. The other two birds made forays outside their home ranges during this period. While Whimbrel 136618 spent most of its time between the neighboring islands of Virgin Gorda and Anegada, it made several brief trips to different islands during its 1.5-year stay in the British Virgin Islands. These forays were to Anguilla, Saint Barts and Saint Martin, Puerto Rico, Saint Kitts and Nevis (Fig. 4). Whimbrel 176013 stayed in Suriname for 144 days (2 Jan 2021–26 Mar 2022), then flew approximately 636 km to Ilha de Maracá, Brazil (2.25247°N, 50.59203°W) for 17 days before returning to Suriname for 92 days (18 Apr–19 Jul 2022) where its tag stopped transmitting.

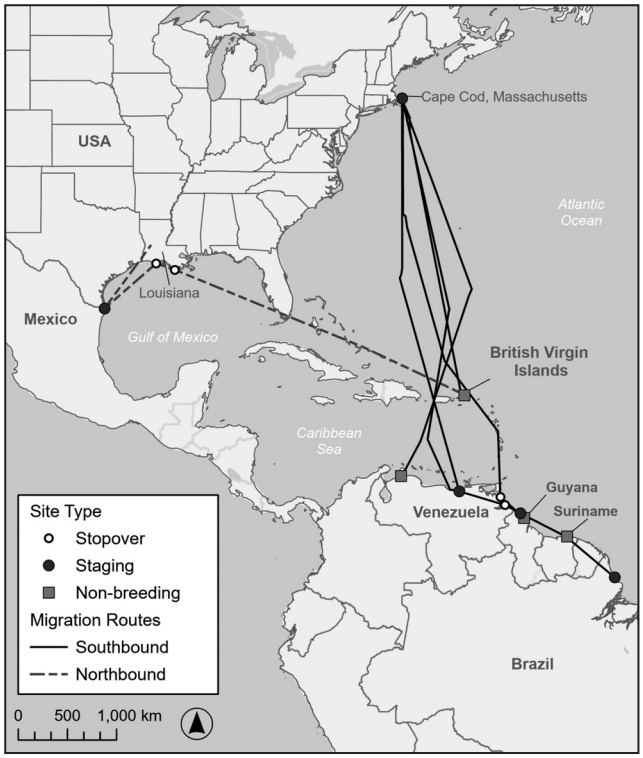

Fig. 2. Seasonal movements of juvenile Whimbrel fitted with satellite transmitters on Cape Cod, Massachusetts, USA, 2015–2022. The routes for southbound (n = 5) and northbound (n = 1) migrations for individual birds are shown.

Light Gray Canvas base map: Esri, TomTom, FAO, NOAA, USGS (2024); World Continents layer: ESRI (2024); US state boundaries: US Census Bureau (2018), South America country boundaries: U.S. Department of State, Office of the Geographer (2013).

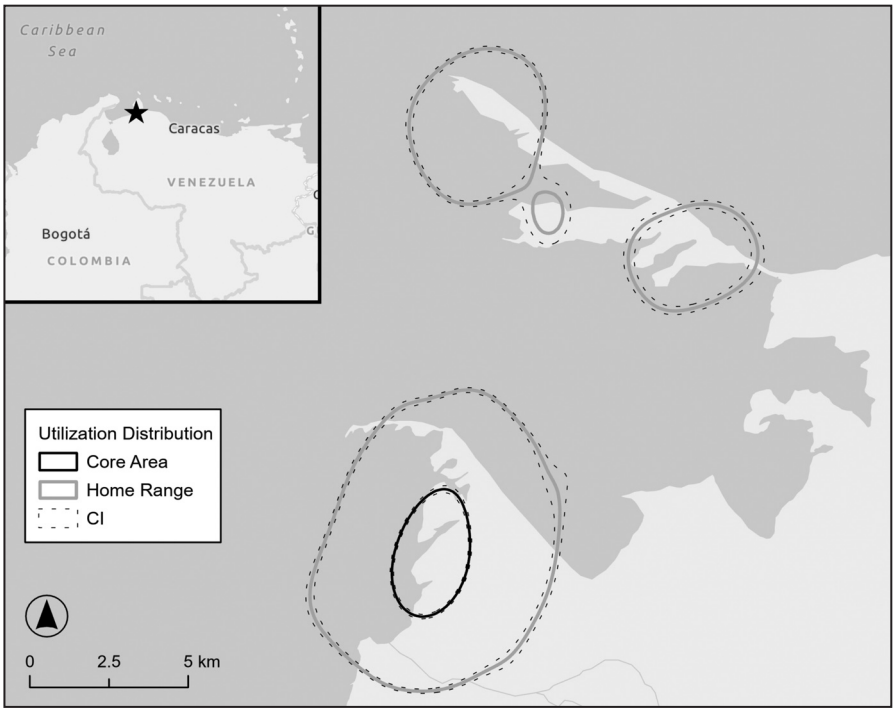

Fig. 3. Example of a non-breeding home range of a juvenile Whimbrel (Tag ID: 136619) fitted with a satellite transmitter. This bird transmitted locations from its non-breeding grounds in Venezuela during 26 September 2017–6 April 2020. The home range and core area are depicted, with 95% CIs. This bird remained within its home range throughout the non-breeding season and the boreal breeding season.

Light Gray Canvas base map: Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS, NPS, USFWS, Earthstar Geographics, NOAA, OpenStreetMap contributors, and GIS User Community.

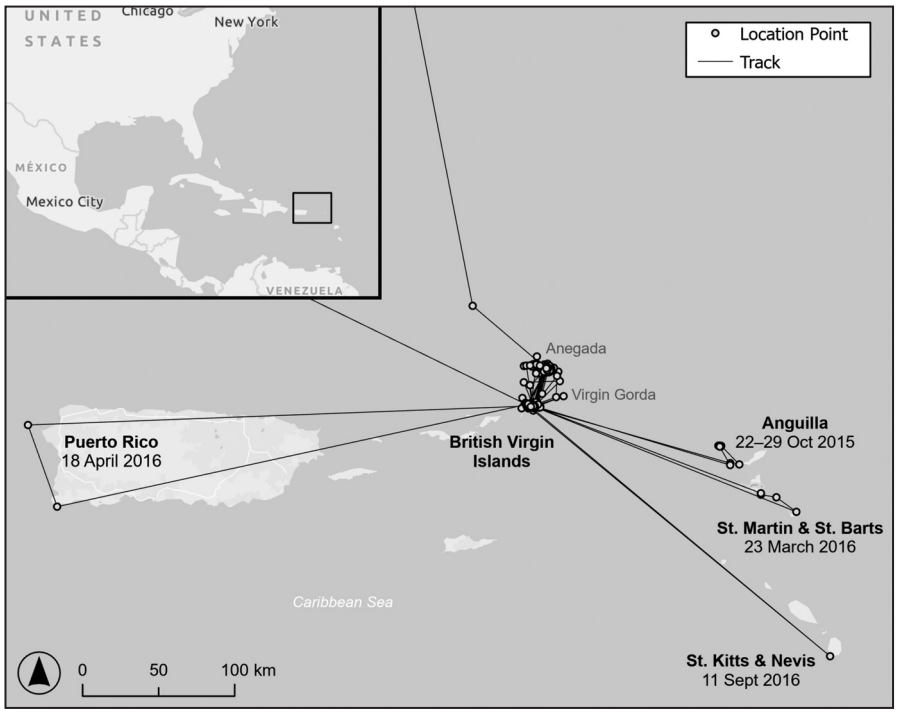

Fig. 4. The non-breeding tracks of a juvenile Whimbrel (Tag ID: 136618) fitted with a satellite transmitter. This bird transmitted from its non-breeding grounds on the British Virgin Islands during 29 September 2015–31 March 2017. The map shows the locations of the bird's forays to other islands during the non-breeding season. The dates of the forays are listed underneath the site labels.

Light Gray Canvas base map: Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS, NPS, USFWS, Esri, TomTom, Garmin, The FAO, NOAA, USGS, NPS, USFWS.

Northbound migration

Whimbrel 136618 spent approximately 1.5 years in the British Virgin Islands before departing for its first northbound migration on 31 March 2017. The travel duration was about seven days with two stopovers in Louisiana, USA along the coast of the Gulf of Mexico (MLOS 4 hrs–1 day). It staged in Mexico (25.92357°N, 97.23701°W) for 21 days. The bird resumed travel for three days until its tag stopped transmitting when over central Louisiana on 2 May 2017.

DISCUSSION

This study established a study site for juvenile Whimbrel in the Western Atlantic Flyway. We identified sites on Cape Cod and captured and deployed transmitters on juveniles. The resulting data enabled us to identify juvenile nocturnal roost sites, including Jeremy Point and North Monomoy, which are also used by adult Whimbrel. The roosts can now be regularly monitored during both the adult and juvenile migratory periods. Improved understanding of this staging area will aid in scaling up juvenile Whimbrel work in the future to address research questions related to the population demography and migratory ecology of juveniles.

We established connectivity between Cape Cod and other sites in the West Atlantic Flyway. All southbound birds used Cape Cod as a terminal staging site before flying across the Atlantic to their non-breeding sites, in the British Virgin Islands, Venezuela, Guyana, Suriname, and Brazil. We also identified stopover and staging areas used by juveniles during north and southbound migration. Despite the low sample size, we had one instance of two birds using the same staging area (aside from Cape Cod), which was in Anzoátegui, Venezuela, near a large petrochemical complex. We documented part of the northbound migration of one bird heading towards the Midcontinent Flyway of the Americas. This confirms similar patterns seen for adult Whimbrel spending the non-breeding period on the north coast of South America (Watts *et al.* 2021b).

Tracking data provided insights into how juvenile Whimbrel use staging and non-breeding sites. We identified temporal patterns in site use on Cape Cod, where birds used separate sites for diurnal and nocturnal activities, which was not the case for the Caribbean and South American sites. The segregation of diurnal and nocturnal activities is similar to that seen in other studies, such as in South Carolina (Sanders *et al.* 2021, Handmaker *et al.* 2024). The interannual site fidelity of adults to foraging grounds found by Handmaker *et al.* (2024) highlights the still unanswered question of whether these preferences are defined by their site selection as juveniles on their first migration. This information gap is one priority question which could be informed by continued tagging of juveniles. For this study, home range estimation was used to characterize the space use of juvenile Whimbrel on their non-breeding grounds. Two birds stayed within their home ranges for the duration of the non-breeding period, while other birds made occasional forays outside their home ranges. Variation in movement patterns on the non-breeding grounds has been documented in Hudsonian Godwits, where some birds had range-resident strategies and others made unpredictable and irregular movements (Basso *et al.* 2023). The application of these strategies by Whimbrel, particularly for juveniles as compared to adults, is a potential area for further study.

Being able to track individual birds during the first years of life provides the opportunity to answer many key questions, ranging from the ontogeny of migration to the survival and recruitment of conservation priority species. There have been many barriers to accomplishing this for shorebirds, including limitations in technology, difficulty of capture, and high mortality rates of juveniles. In this study, we confirmed a delayed maturation period in two Whimbrel, with both birds spending more than one calendar year on their non-breeding grounds (British Virgin Islands and Venezuela). This is the first use of tracking data to document the duration of this maturation period in a shorebird. This extended length of stay at these non-breeding sites underscores the importance of this period for the population's overall health. As this work continues, a priority will be to identify these locations and prioritize them for on-the-ground research. Mark-recapture research on Semipalmated Sandpipers *Calidris pusilla* on the non-breeding grounds has shown increased survival by 'oversummering' birds, i.e. birds that delay return to the breeding grounds for one or more seasons, suggesting that this benefit is sufficient to compensate for foregone breeding opportunities (Tavera *et al.* 2020). Oversummering of adult Hudsonian Godwits has also been documented (Navedo & Ruiz 2020). This mounting evidence has the potential to redefine conservation plans for shorebirds in the southern hemisphere.

This study focused on juvenile Whimbrel movement and timing but does not represent a dataset sufficient to address demographic attributes such as survival and recruitment. Future work should scale up juvenile research to properly address those questions and build the results into a demographic model for Whimbrel. Cape Cod also provides a rare opportunity to study adult and juvenile Whimbrel alongside each other. Future studies could include topics such as behavior of adults and juveniles at a terminal staging area, survival rates of juveniles and adults staging at the same location, as well as overall migratory efficiency, similar to findings presented by Carneiro *et al.* (2024) for Eurasian Whimbrel in Iceland. Tracking studies focused on juvenile migration ecology in White Storks *Ciconia ciconia* have indicated that juveniles expended more energy in flight and did not compensate for their higher flight costs by increased refueling or resting during migration (Rotics *et al.* 2016). While storks are soaring birds, these potential causes of juvenile mortality may translate to shorebirds as well, and this could be a future line of inquiry with the appropriate type of transmitter data.

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REFERENCES

Bainbridge, I.P. & C.D.T. Minton. 1978. The migration and mortality of the Curlew in Britain and Ireland. *Bird Study* 25: 39–50.

Ballantyne, K. & E. Nol. 2015. Localized habitat change near Churchill, Manitoba and the decline of nesting Whimbrels (*Numenius phaeopus*). *Polar Biology* 38: 529–537.

Bart, J., S. Brown, B. Harrington & R.I.G. Morrison. 2007. Survey trends of North American shorebirds: population declines or shifting distributions? *Journal of Avian Biology* 38: 73–82.

Basso, E., J. Horstmann, E. Rakhimberdiev, J.M. Abad-Gómez, J.A. Masero, J.S. Gutiérrez, J. Valenzuela, J. Ruiz & J.G. Navedo. 2023. GPS tracking analyses reveal finely-tuned shorebird space use and movement patterns throughout the non-breeding season in high-latitude austral intertidal areas. *Movement Ecology* 11: 55.

Calabrese, J.M., C.H. Fleming & E. Gurarie. 2016. ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology & Evolution* 7: 1124–1132.

Calenge, C. 2023. *Home range estimation in R: the adehabitatHR Package.* R package version 0.4.21. R Foundation for Statistical Computing, Vienna, Austria. Accessed 11 Nov 2023 at: *https://cran.r-project.org/web/packages/adehabitatHR/index.html*

Carneiro, C., T.G. Gunnarsson, T. Kaasiku, T. Piersma & J.A. Alves. 2024. Icelandic Whimbrel first migration: Non-stop until West Africa, yet later departure and slower travel than adults. *Ibis* 166: 715–722.

Collecte Localisation Satellites (CLS). 2011. *Argos user's manual*. Accessed at: *http://www.argos-system.org/manual/*.

eBird. 2024. eBird: an online database of bird distribution and abundance. eBird, Cornell Lab of Ornithology, Ithaca, NY, USA. Accessed 2 Feb 2024 at: *http://www.ebird.org.*

Fancy, S.G., L.F. Pank, D.C. Douglas, C.H. Curby, G.W. Garner, S.C. Amstrup & W.L. Regelin. 1988. *Satellite telemetry: a new tool for wildlife research and management*. Resource Publications, No. 172. US Fish and Wildlife Service,Washington DC, USA.

Fleming, C.H., W.F. Fagan, T. Mueller, K.A. Olson, P. Leimgruber & J.M. Calabrese. 2015. Rigorous home range estimation with movement data: a new autocorrelated kernel density estimator. *Ecology* 96: 1182–1188.

Handmaker, M.C., F.J. Sanders, A.D. Smith, E.P. Shealy, N. Fontaine, M.B. Kaplin, J.M. Thibault, M.C. Martin, C. Duquet, A.V. Sterling & N.R. Senner. 2024. Individual foraging site fidelity persists within and across stopover seasons in a migratory shorebird, *Numenius phaeopus* (Whimbrel). *Ornithology* 141: 1–14.

Hines, C., L. Duval, B.D. Watts, G. Van Horn & E. Miller. 2023. Citizen science photographs indicate different timing and location use of migrating adult and juvenile Whimbrels. *Ornithological Applications* 125: 1–10.

International Shorebird Survey (ISS). 2024. *Shorebird Survey Data collected by citizen scientists across the Western Hemisphere.* Manomet Conservation Sciences, Plymouth, MA, USA. Accessed 1 Jul 2024 at: *https://www.manomet.org/iss-map/*.

Kus, B.E., P. Ashman, G.W. Page & L.E. Stenzel. 1984. Age-related mortality in a wintering population of Dunlin. *Auk* 101: 69–73.

Mackay, G.H. 1892. Habits of the Hudsonian Curlew in Massachusetts. *Auk* 9: 345–352.

Morrison, R.I.G., D.S. Mizrahi, R.K. Ross, O.H. Ottema, N. de Pracontal & A. Narine. 2012. Dramatic declines of Semipalmated Sandpipers on their major wintering areas in the Guianas, northern South America. *Waterbirds* 35: 120–134.

Navedo, J.G. & J. Ruiz. 2020. Oversummering in the southern hemisphere by long-distance migratory shorebirds calls for reappraisal of wetland conservation policies. *Global Ecology & Conservation* 23: e01189.

Pyle, P. 2008. *Identification Guide to North American Birds. Part II*. Slate Creek Press, Bolinas, CA, USA.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Accessed at: *https://www.r-project.org*.

Rotics, S., M. Kaatz, Y.S. Resheff, S.F. Turjeman, D. Zurell, N. Sapir, U. Eggers, A. Flack, W. Fiedler, F. Jeltsch, M. Wikelski & R. Nathan. 2016. The challenges of the first migration: movement and behaviour of juvenile vs. adult white storks with insights regarding juvenile mortality. *Journal of Animal Ecology* 85: 938–947.

Sæther, B.E. & Ø. Bakke. 2000. Avian life history variation and contribution of demographic traits to the population growth rate. *Ecology* 81: 642–653.

Sandercock, B.K. 2003. Estimation of survival rates for wader populations: a review of mark-recapture methods. *Wader Study Group Bulletin* 100: 163–174.

Sanders, F.J., M.C. Handmaker, A.S. Johnson & N.R. Senner. 2021. Nocturnal roost on South Carolina coast supports nearly half of Atlantic coast population of Hudsonian Whimbrel *Numenius hudsonicus* during northward migration. *Wader Study* 128: 117–124.

Schulte, S., S. Brown, D. Reynolds & American Oystercatcher Working Group. 2010. American Oystercatcher Conservation Action Plan for the United States Atlantic and Gulf Coasts. Version 2.1. Accessed 20 Jun 2024 at: *https://amoywg.org/wp-content/uploads/2011/11/ American-Oystercatcher-U.S.-ConservationPlan-10-02-28-v2.1.pdf.*

Silva, I., C.H. Fleming, M.J. Noonan, J. Alston, C. Folta, W.F. Fagan & J.M. Calabrese. 2021. Auto-correlation-informed home range estimation: A review and practical guide. *Methods in Ecology & Evolution* 13: 534–544.

Skeel, M.A. 1983. Nesting success, density, philopatry and nest-site selection of the Whimbrel (*Numenius phaeopus*) in different habitats. *Canadian Journal of Zoology* 61: 218–225.

Smith, P.A., **A.C. Smith**, **B. Andres**, **C.M. Francis**, **B. Harrington**, **C. Friis**, **R.I.G. Morrison**, **J. Paquet**, **B. Winn & S. Brown.** 2023. Accelerating declines of North America's shorebirds signal the need for urgent conservation action. *Ornithological Applications* 125: 1–14.

Tavera, E.A., **G.E. Stauffer**, **D.B. Lank & R.C. Ydenberg.** 2020. Oversummering juvenile and adult Semipalmated sandpipers in Perú gain enough survival to compensate for foregone breeding opportunity. *Movement Ecology* 8: 42.

Veit, R.R. & W.R. Petersen. 1993. *Birds of Massachusetts*. Massachusetts Audubon Society, Natural History of New England Series, Boston, MA, USA.

Warnock, N. 2010. Stopping vs. staging: the difference between a hop and a jump. *Journal of Avian Biology* 41: 621–626.

Watts, B.D. & B.R. Truitt. 2011. Decline of Whimbrels within a Mid-Atlantic staging area (1994–2009). *Waterbirds* 34: 347–351.

Watts, B.D., **F.M. Smith**, **D.J. Hamilton**, **T. Keyes**, **J. Paquet**, **L. Pirie-Dominix**, **J. Rausch**, **B. Truitt**, **B. Winn & P. Woodard.** 2019. Seasonal variation in mortality rates for Whimbrels (*Numenius phaeopus*) using the Western Atlantic Flyway. *Condor* 121: 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 & P. Woodard.** 2021a. The costs of using night roosts for migrating whimbrels. *Journal of Avian Biology* 52: jav.02629.

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 & P. Woodard.** 2021b. The annual cycle for whimbrel populations using the Western Atlantic Flyway. *PLOS ONE* 16: e0260339.

Weiser, E.L., **S.C. Brown**, **R.B. Lanctot**, **H.R. Gates**, **K.F. Abraham**, … **& B.K. Sandercock.** 2018. Effects of environmental conditions on reproductive effort and nest success of Arctic-breeding shorebirds. *Ibis* 160: 608–623.

Wilson, S. & K. Martin. 2012. Influence of life history strategies on sensitivity, population growth and response to climate for sympatric alpine birds. *BMC Ecology* 12: 9.