AMERICAN WOODCOCK (*SCOLOPAX MINOR*) MIGRATION ECOLOGY IN EASTERN NORTH AMERICA – 2023 Annual Report

Compiled by: Rachel Darling[a], Liam Berigan[a], Alexander Fish[a], Sarah Clements[a], Kylie Brunette[a], Colby Slezak[b], Kayleigh Filkins[c], Amber Roth[a], Scott McWilliams[b], Jacob Straub[c] and Erik Blomberg[a]

[a]Department of Wildlife, Fisheries, and Conservation Biology, University of Maine

[b]Department of Natural Resources Science, University of Rhode Island

[c]Department of Environmental Science and Ecology, SUNY Brockport

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The Eastern Woodcock Migration Research Cooperative is a collaborative group partnered to understand the migratory ecology of American Woodcock in eastern North America. This project would not have been possible without the support from multiple state, federal, international, non-profit agencies, and universities. *This document contains draft information that has not yet been subject to peer review. As such any results or information reported herein should be cited as unpublished data, and we anticipate interpretation may change as additional years of data are collected.*

Cover photo: Woodcock waiting to be tagged in Cooks Brook, Nova Scotia, October 2023. Held by University of Maine postdoctoral research associate Sarah Clements. Photo credit to Kylie Brunette, master's student at the University of Maine.

Executive Summary

The American Woodcock (*Scolopax minor*) is a migratory forest bird that has experienced population declines of 1.1 percent per year for the past five decades. Woodcock migration had traditionally been challenging to study, leading to limited information about migratory ecology to inform management. We initiated the Eastern Woodcock Migration Research Cooperative in 2017 to provide insights into woodcock migration in the Eastern Management Region, and we have since expanded our focus to the species' entire North American range. This report documents data collection and preliminary findings from the past year, presents major results to date, and describes our future directions. Past achievements can be found in our previous year's reports by visiting woodcockmigration.org/research. Highlights from this report include:

- ***Field data collected to date:*** From Fall 2017 – Spring 2023, we deployed 596 GPS transmitters on woodcock captured in 15 states and 3 Canadian provinces throughout eastern North America, which provided data on 517 migration attempts and 405 full migratory paths. We

collected feather or blood samples from the majority of marked woodcock, which we will use to assess woodcock population structure via genomic and isotopic methods.

- ***Spring male migration and the singing ground survey:*** Our manuscript evaluating the phenology of spring migration by male woodcock and assessing several assumptions of the American woodcock singing ground survey (SGS) was published in the Journal of Wildlife Management (doi: 10.1002/jwmg.22488, also available on the EWMRC website). Based on data from 133 males that migrated during spring, we asked whether the SGS window (20-day period during which the survey may be conducted) occurred after the completion of migration in each SGS zone, and whether males settled within the approximate spatial coverage of the SGS. We found SGS timing was relatively consistent with migration except in the northern most zone (zone 5), and that 90% of males settled into breeding territories within SGS coverage. This work was also presented at the 2023 American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada joint meeting in August 2023, and the Maine State Chapter of The Wildlife Society Meeting in December 2023.

- ***Woodcock migration strategies:*** A manuscript describing migration strategies in woodcock is currently in review at Ornithology. We used data from 300 individuals in a principal components analysis (PCA) to evaluate variation in migration strategies based on characteristics of migration paths and stopping events. We also used these results to test for effects of body condition, age-sex class, and starting and ending location on migration strategy. The PCA did not show evidence for discrete migration strategies, but rather continuous gradients most heavily driven by migration distance and duration, departure timing, and stopping behavior. Starting and ending latitude and longitude explained more variation in migration strategies than body condition or age-sex class. A portion of this project was presented as a poster at the 2023 American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada joint meeting in August 2023.

- ***Female reproduction and migration:*** During spring 2021 and 2022, we documented nesting attempts of GPS-marked birds and confirmed 26 nests via field observation. In doing so, we documented unprecedented observations of females making long-distance migrations (> 500 kilometers) between successive nesting attempts. This suggests woodcock may possess an itinerant breeding strategy, where individuals may reproduce in multiple regions connected via migration. Using these field-verified nests as a validation dataset within the nestR package, we mined the larger EWMRC dataset for other female nesting attempts and found 337 likely attempts from more than half (n = 154 of 272) of females with sufficient tracking data after January 1. This work is led by Colby Slezak at the University of Rhode Island, and is currently under review at the journal Ecology Letters.

- ***Multi-season species distribution models and habitat conservation:*** We created a spatial decision support system for multi-season habitat use of woodcock in Pennsylvania. We modeled woodcock breeding and migratory habitat distributions and integrated the predictions into a Shiny application (Woodcock Priority Area Siting Tool, W-PAST). W-PAST accepts user input through breeding and migratory season weights, allowing user customization based on area-specific management priorities. We found that woodcock tend to use different habitats during breeding season than they do during migration, indicating that conservation of breeding habitat alone is unlikely to also conserve migratory habitat. We also found that woodcock breeding and migratory habitat in Pennsylvania is unevenly distributed at a regional scale. This work is led by PhD candidate Liam Berigan, and is currently under review at the journal Biological Conservation.

- ***Adapting hidden Markov models to data from small GPS transmitters for tracking migratory birds:*** We used hidden Markov models on our woodcock dataset to determine if additional data streams would improve predictions of migratory states, further describe the migratory phenology of woodcock, and characterize long-distance movements outside of the migratory season. We found that including additional data streams greatly improved the performance of hidden Markov models, and we observed a small proportion of birds that underwent non-migratory dispersal (<1% of birds available), recursive foray loops (4%), and summer migrations (5%). Only 3% of woodcock skipped migration entirely during at least 1 season, and of 5 marked woodcock that skipped migration and were tracked across multiple seasons, all 5 migrated during the second season. These new approaches to migration classification will be important for informing future analyses, especially when using sparse and irregular tracking data.

- Genomic analysis of population structure: During spring/summer 2023 we obtained the first results from 192 genomic samples (blood or feather) from woodcock with complete or near-complete migration paths that included both wintering and summering locations. A Bayesian clustering analysis was unable to recover any population structure, including no discernible genetic differences among birds summering in the EMR and the CMR, and no spatial structure in general. This suggests regular gene flow and genetic admixture across the woodcock's range. However, our sample of woodcock from the CMR is limited compared to our EMR sample, and we are focused on additional sampling of migrant woodcock in the CMR to bolster sample sizes.

- ***Work in progress:*** We will continue to collect data at a subset of field sites during Spring and Fall 2024. We also plan to expand analyses in the coming year to address the survival of woodcock throughout migration, habitat selection throughout the full annual cycle, responses of woodcock to light pollution during migration, flight altitudes in migrating woodcock, resource selection of woodcock breeding in New York, woodcock ecology in West Virginia, and woodcock use of stopovers in urbanized landscapes.

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Introduction

The American Woodcock (*Scolopax minor*; woodcock hereinafter) is a migratory forest-dwelling scolopacid that has experienced long-term declines of 1.1% per year over the past 50 years (Seamans and Rau 2018). Woodcock are distributed throughout eastern North America; primarily breeding in the northern United States and southern Canada and overwintering in the southern United States. The species is managed as two discrete populations associated with the Central and the Eastern Management Regions (*Figure 1*). Woodcock generally migrate south between October – December and north between January – April (Krementz et al. 1994, Butler 2003, Meunier et al. 2008, Moore 2016). Prior studies of woodcock migration were principally derived from observations of local changes in woodcock abundance (e.g. arrival of spring migrants) and radio-tracking studies at breeding, wintering, and stopover sites. While this information is useful, it is inherently limited in scope and cannot be applied broadly across the species' range. This knowledge gap prompted the Association of Fish and Wildlife Agencies to identify migratory ecology as one of the woodcock's greatest research needs (Case & Associates 2010).

Tracking woodcock throughout migration presents numerous challenges, as individuals must be continually relocated over vast distances, almost always spanning numerous states and often two countries (Myatt and Krementz 2007, Klaassen et al. 2014). Recent advances in transmitter tracking technologies allow for woodcock to be tracked using satellite transmitters (Moore 2016). Satellite transmitters can now simultaneously collect global positioning system (GPS) location data and remotely transmit locations to a central database via satellite or cellular networks. Between 2014 and 2016, Moore (2016) used satellite transmitters to track migrating woodcock in the Central Management Region, but were unable to track more than a few woodcock that migrated into the eastern half of the range. To that end, we created the Eastern

Woodcock Migration Research Cooperative with the goal of describing the migratory ecology of woodcock in the Eastern Management Region using satellite-enabled telemetry.

In this report, we document data collected during the project's first six years, summarize woodcock observations during Fall 2022-Summer 2023 (see appendices), highlight several noteworthy findings from the past year, present scientific products from the collaborative to date, and provide a description of work in progress and outreach accomplishments. Previous years' reports can be found by visiting woodcockmigration.org/research.

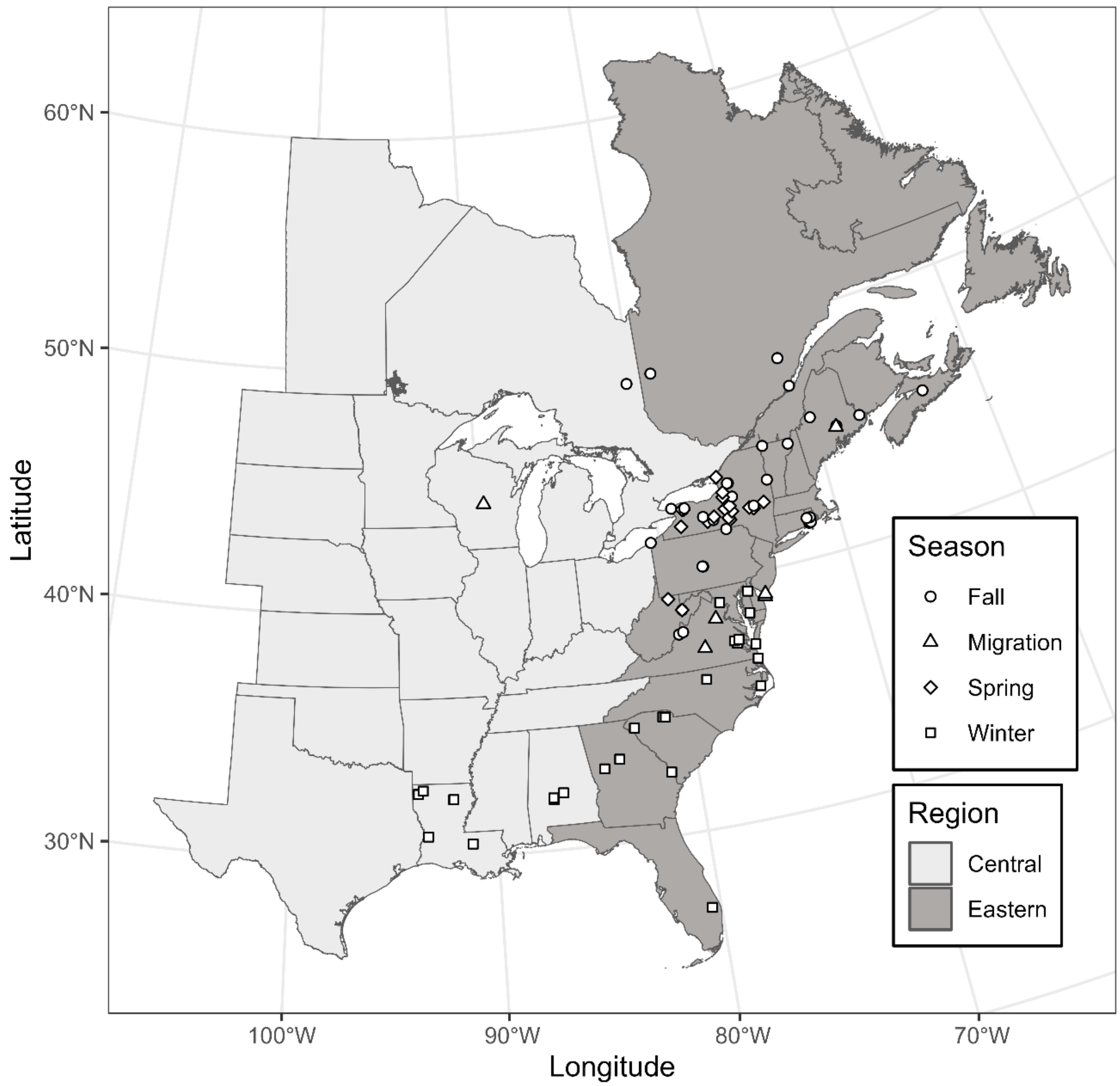

Figure 1. American Woodcock Central (light gray) and Eastern (dark gray) Management Regions, with white points indicating capture locations and shape of the point indicating the season during which captures occurred.

Methods

Study Area

The Eastern Woodcock Migration Research Cooperative study area is primarily comprised of the Eastern Woodcock Management Region, the spatial unit at which the United States Fish and Wildlife Service and Environment and Climate Change Canada manage woodcock populations. During the fall (September – October), we focused capture efforts in ME, NY, PA, RI, VA, VT, and WV in the U.S., as well as NS, ON, and QU in Canada. During winter (December – February), we focused captures in AL, FL, GA, LA, MD, NC, NJ, SC, and VA. During the spring (April – June), we focused captures in NY and WV (see *Figure 1* for locations). We relied on the knowledge of local partners to identify areas suitable for woodcock capture within states and provinces, and we deployed transmitters on a wide variety of land ownership types, including state, federal, non-governmental organization, and private. As woodcock departed for spring and fall migration, they left capture locations and migrated either north or south, respectively, traversing multiple states and provinces throughout the eastern United States and Canada.

Capture

We captured woodcock using mist nets during crepuscular flights (Sheldon 1960) and by spot-lighting roosting birds (Rieffenberger and Kletzly 1966, McAuley et al. 1993). We set mist net arrays near roosting fields, travel corridors, and forested wetlands to capture birds as they left diurnal use areas and flew to night roosts. Additionally, we used spotlights and thermal imaging scopes to locate woodcock roosting in fallow or agricultural fields and captured them using handheld nets. Once captured, we aged woodcock to two ages classes (adult [after hatch year or after second year; > 1 year old] or young [hatch year or second year; < 1 year old]) using wing plumage characteristics and sexed (male or female) them using a combination of wing plumage and bill length (Mendall and Aldous 1943, Martin 1964). Woodcock were fitted with a Lotek PinPoint 75, 120, or 150 ARGOS-compatible satellite transmitter, attached with a leg-loop style harness (Moore 2016). The GPS collected locations at pre-programmed dates and times, and transmitted data to a central database using the ARGOS satellite system. We stopped receiving locations when birds either dropped their transmitter or died, thereby causing the transmitter to rest on the ground and attenuate the signal, or if the transmitter's battery died or the transmitter otherwise failed. We have developed methods to differentiate tag loss/failure from mortality to estimate survival from the GPS location data (see *Work in Progress*).

Transmitter Schedules

Transmitters were manually programmed using Lotek PinPoint Host software (Lotek Wireless Inc., Newmarket, Ontario, CA), which allowed us to specify the exact date and time locations were collected. Transmitters had limited battery life and were expected to collect a maximum of 75, 100, and 125 locations for the PinPoint 75, 120, and 150 tags, respectively, before losing power. We created three location collection schedules; frequent (one location per day), infrequent (one location every few days), and hybrid (combinations of frequent and infrequent periods) to maximize the amount of data we collected for each woodcock. Hybrid schedules contained a frequent collection period (~30 days) during the peak of migration, and infrequent collection periods before and after the frequent period. Frequent and infrequent schedules were used on both sexes during both fall and spring migration, with hybrid schedules used during spring migration as the potential migration periods exceeded the expected number of GPS locations possible under a frequent schedule. Frequent schedules are useful to evaluate fine scale movement and provide the finest resolution (i.e., one day) to document stopover (resting periods during migration) ecology. Infrequent schedules allow for woodcock to be tracked for longer periods of time, thus possibly providing data on both spring and fall migration for an individual bird. Infrequent schedules also increased the probability of receiving future data transmissions when individuals used stopover sites with poor satellite signal and failed to upload locations (e.g., mountainous areas with a steep slope).

From Fall 2017 – Spring 2020, we set these transmitter schedules to take locations exclusively during the afternoon to capture woodcock stopover habitat use. Beginning in Fall 2020, PinPoint tags were manufactured to record the altitude of GPS locations, which introduced the capability to differentiate between night flight and night stopover locations. Accordingly, in Fall 2020 we began altering our transmitter schedules to take advantage of the ability to capture migratory flight points. We created schedules that took a combination of day and night locations, and schedules that took night locations only, which we randomly assigned to woodcock, attempting to control for age and sex ratios by program and capture location. In Fall 2023, we created an overwater schedule (2-3 locations taken per night) to try to capture the routes woodcock use when they leave Nova Scotia. Location data were transmitted to a remote database using the ARGOS satellite system after every third GPS location was collected. We manually downloaded woodcock locations every 1 to 5 days and used Movebank (Kays *et al.* 2022) to store all location data.

For all woodcock movement paths, we classified locations according to stage of migration and their position in the annual cycle. The beginning of migratory movements were defined by first point in a sustained, directional movement of > 16.1 km following capture, while the last step > 16.1 km defined the end of migratory movements. We use 16.1 km based on the distribution of all steps within the data, which illustrate a bimodal distribution of movements with a clear threshold around 16.1 km (Blomberg et al. 2023).This is an increase from the 7 km threshold used in previous annual reports. If a bird stopped transmitting before the end of its migration, we determined whether its final step was migratory or post-migratory based on a hidden Markov model framework (see Berigan et al. in prep ***below***). If the last location received from the bird was a part of a migratory step, then the migratory trajectory was classified as incomplete and excluded from assessments of distance traveled during migration and time spent migrating (reported in table A2). Additional analyses were performed for specific objectives, as described in each corresponding results section.

Data collected to date

Since the EWMRC began in Fall 2017, we have deployed 596 transmitters on birds captured in 18 states and provinces (*Table A1.* American Woodcock captured and tagged with satellite GPS transmitters in each state/province collaborating in the Eastern Woodcock Migration Research Cooperative, summarized by year, age, and sex.). These transmitters have gathered over 34,000 locations (*Figure 2*, *Figure 3*), and during the Fall 2022 and Spring 2023 migration seasons alone, we recorded over 55,000 kilometers of migratory movements from 76 woodcock marked during the past year. Number of woodcock captured and data collected for the project as a whole have been evenly distributed among age and sex classes (*Figure 2*), and while location data is clustered the Eastern Management Region, we have collected woodcock locations from nearly all states and provinces within the species' range (*Figure 3*). In total, we have documented 517 migration attempts and 405 full migratory paths (

Table A2. Number of attempted and complete migratory movements by GPS-tagged American Woodcock by season from Fall 2017 through Spring 2022. Complete migratory movements are a result of actual migratory completion as described in Transmitter Schedules *above*; in some instances, tag battery failure occurred before completion could be confirmed.). Since altitude capacity was introduced on PinPoint transmitters in Fall 2020, we have also recorded at least 139 presumed night flight locations that can be used to characterize woodcock flight altitudes during migration.

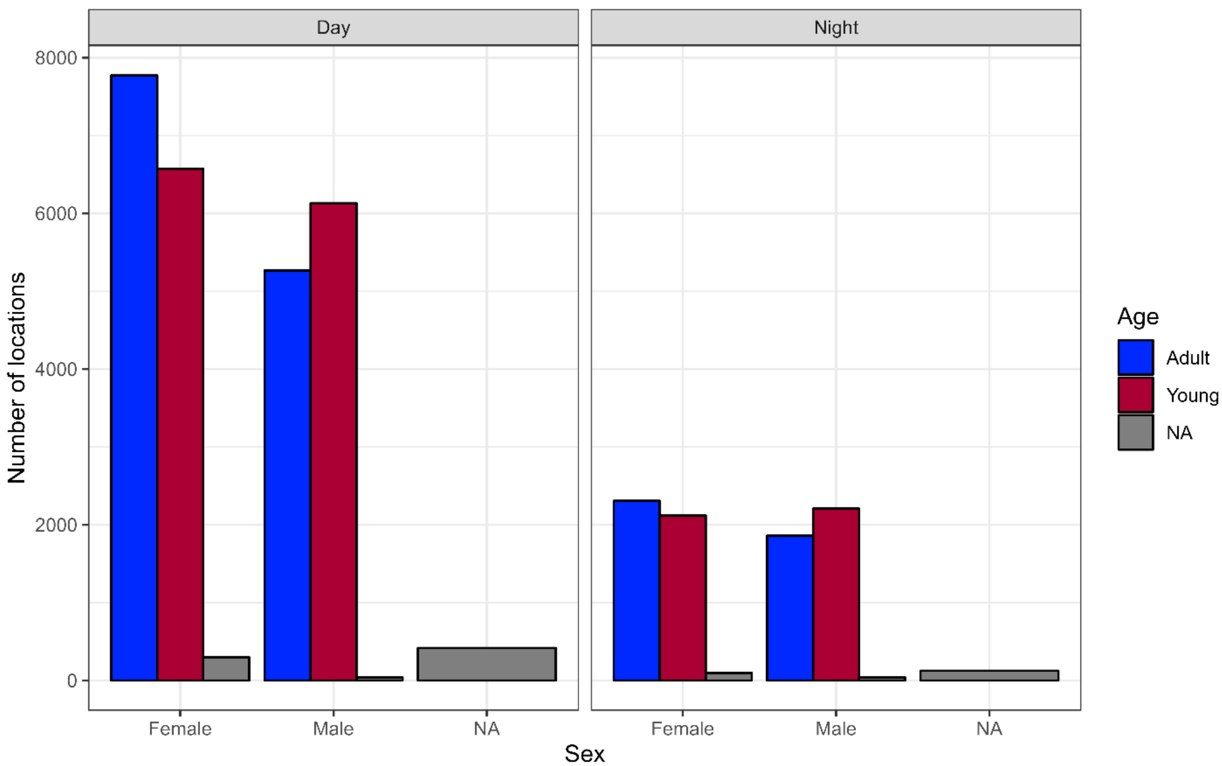

Figure 2. Counts of GPS locations recorded by tagged woodcock from Fall 2017 – Summer 2023. Over 34,000 locations have been gathered since the project began, including day and night locations and large sample sizes from each combination of sex and age classes. 'NA' reflects birds not assigned a sex or age class at capture.

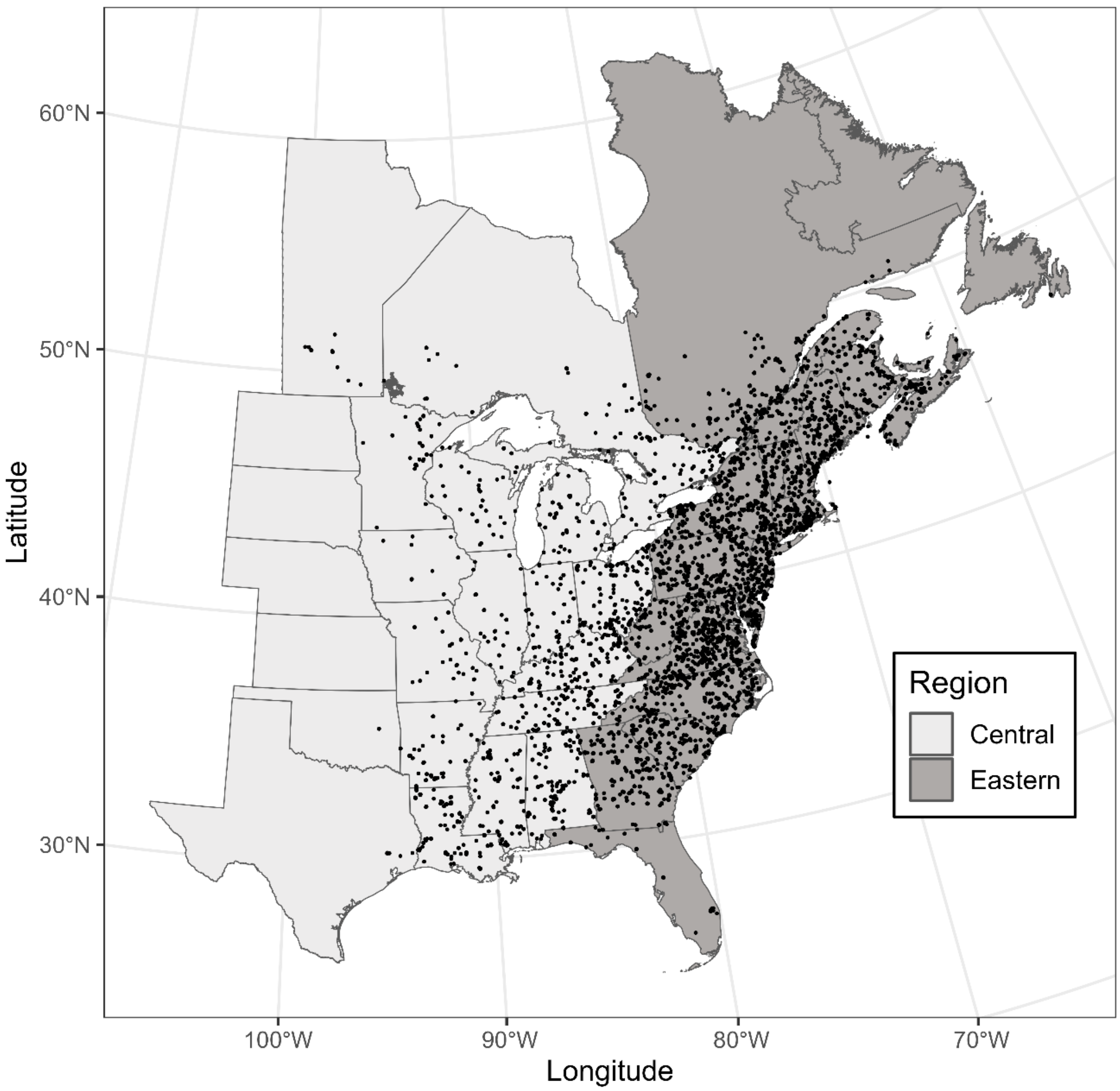

Figure 3. GPS locations (black points) collected by woodcock marked through the EWMRC from Fall 2017 – Summer 2023. Over 34,000 locations have been gathered since the project began. Location density is highest in the Eastern Management Region, but locations can be found throughout the entirety of the woodcock's range.

Recent Publications and Publications in Prep

1. The American Woodcock singing ground survey largely conforms to the phenology of male woodcock migration (Lead: Erik Blomberg, *published in the Journal of Wildlife Management*)

Abstract: American woodcock are monitored, in part, by counts of displaying male woodcock collected via the American Woodcock Singing Ground Survey (SGS), which suggests long-term, range-wide declines in woodcock populations. Data from the SGS have been used extensively to develop conservation plans, direct management actions, and understand causes of decline. To avoid bias, the SGS should be timed to avoid spring migration, and the distribution of survey routes should coincide with woodcock breeding distribution. Our objectives for this research were to evaluate SGS timing with the phenology of male woodcock migration, relate the spatial coverage of the SGS to male woodcock breeding distributions, and explore other sources of variation in woodcock migration timing. We marked 133 male woodcock captured throughout eastern North America with global positioning system (GPS) transmitters during 2019–2022 and compared the timing of their spring migration with the spatiotemporal stratification of the SGS. Most woodcock (74%) completed migration prior to the onset of the SGS. In the northernmost SGS zone, a greater percentage of males (34%) continued migration during the survey window; however, the influence of this mismatch is offset because SGS routes were run more frequently during the second half of the window in the years 2019–2022. Young woodcock completing their first spring migration took an average of 8.6 days longer to do so compared to adults, and so were more likely to migrate during the SGS window. We found little evidence that timing of migration varied among years. Existing SGS routes cover the majority of male woodcock post-migratory breeding distribution, with 90% of male woodcock establishing final breeding sites within the spatial coverage of the SGS. Our results confirm the SGS includes some migrating

males, with the proportion relative to resident breeding males increasing in more northern survey strata. Our data suggests these errors are unlikely to bias trend estimates at large scales (e.g., within woodcock management regions), but there may be potential for bias at more local scales (e.g., state or provincial population indices). A pdf of the full-text can be found here.

2. Lack of evidence for discrete migration strategies in American Woodcock suggests potential for species' resilience (Lead: Sarah Clements; *in review at Ornithology*)

Abstract: Diversity in behavior is important for migratory birds in adapting to dynamic environmental and habitat conditions and responding to global change. Migratory behavior can be described by a variety of factors that comprise migration strategies. We characterized variation in migration strategies in American Woodcock using GPS data from approximately 300 individuals tracked throughout eastern North America. We classified woodcock migratory movements using a step-length threshold, and calculated characteristics of migration related to distance, path, and stopping events. We then used principal components analysis (PCA) to ordinate variation in migration characteristics along axes that explained different fundamental aspects of migration, and tested effects of body condition, age-sex class, and starting and ending location on PCA results. The PCA did not show evidence for clustering, suggesting a lack of discrete strategies among groups of individuals; rather, woodcock migration strategies existed along continuous gradients driven most heavily by metrics associated with migration distance and duration, departure timing, and stopping behavior. Body condition did not explain variation in migration strategy during the fall or spring, but during spring adult males and young females differed in some characteristics of migration. Starting and ending latitude and longitude, particularly the northernmost point of migration, explained up to 61% of the variation in any one axis of migration strategy. Our results reveal gradients in migration behavior of woodcock, and

this variability should increase the resilience of woodcock to future anthropogenic landscape and climate change.

The manuscript from this project has been submitted to Ornithology and is under review. A portion of the project was also presented as a poster at the 2023 American Ornithological Society and Society of Canadian Ornithologists/Société des ornithologistes du Canada joint meeting in August 2023. The poster can be accessed via this link.

3. American woodcock migration phenology in eastern North America: implications for hunting season timing (Lead: Alexander Fish; *in review at Journal of Wildlife Management*)

Abstract: Understanding the phenology of migration is fundamental to management of migratory gamebirds, in part because of the role migratory timing plays in setting harvest regulations. Migratory timing is particularly important for determining appropriate dates for hunting seasons, which may be selected to coincide with major periods of migration, according to local management objectives. We used GPS transmitters to track American woodcock, characterize the timing of woodcock migration, and identify sources of variation in timing relative to current hunting season structures in eastern North America. We captured 304 woodcock in 3 Canadian provinces and 12 US states from 2017 to 2020, primarily within the Eastern Woodcock Management Region. Using locations collected every 1.7 days on average, we assessed whether initiation, termination, or stopover timing of woodcock migration during fall and early spring varied geographically, differed among age and sex classes, or was influenced by individual body condition. During fall, woodcock migrating from summer use areas farther north and west (e.g., Ontario, Quebec) initiated and terminated migration earlier than woodcock migrating from areas farther south and east (e.g., Rhode Island). Adult woodcock made longer

multiday stopovers that were 3 days longer, on average, than juveniles, and females made more stopovers on average (8.0 stopovers) compared to males (6.1 stopovers). During the onset of spring migration, woodcock that wintered farther west initiated migration before birds that spent the winter farther east, and males initiated migration on average six days earlier than females. Under current 45-day frameworks in the US, hunting seasons are generally consistent with migration phenology, with the greatest deviation at mid-latitudes and for states that split hunting seasons.

4. Female nesting and movements (Lead: Colby Slezak, URI; *in review at Ecology Letters*)

Abstract: During 2020-2022, we deployed GPS tags on females throughout the fall and winter with the intent of finding nest attempts the following spring. From late January-June 2020-2022, Colby Slezak (PhD student, URI) closely monitored GPS points to detect nesting females, with nesting behavior determined based on consistent locations between consecutive points. When a nest was suspected, nearby EWMRC collaborators travelled to the suspected nest site and attempted to visually verify that a female was on a nest.

We captured and tagged 37 and 35 females during the 2020-2021 and 2021-2022 field seasons respectively. We field-verified 26 nesting attempts (2021: *n*=16; 2022: *n*=10) from 22 (2021: *n*=13; 2022: *n*=9) individual females, including 4 females that nested more than once. Three of the renesting females migrated a substantial distance northward from their initial nest attempt (range: 199-889 km). We used the movement patterns of field-verified nesting females to verify the accuracy of the find_nests() function in the nestR package (Picardi et al. 2020), and then used this function to identify nests that we were unable to field-verify, and to retroactively locate nesting females tagged by other collaborators from 2019-2022. The function successfully located 92% (24 of 26) of our field-verified nesting attempts and identified 337 likely nesting attempts from 154 of the 272 females that transmitted locations on or after 1 January. The females not classified as nesting (n=118) were tracked for short periods of time (43.69 days, 95% CI: 37.62 to 49.75 days) and half of which had ≤ 35 transmissions, a period too short to reliably detect whether these females attempted nesting. Like Montague (2005), we found that a majority of nests were initiated no earlier than mid-February; only 73 (22%) of the 337 were initiated prior to 20 February, and all in more southerly areas of the woodcock's range (below 40ºN; Sheldon 1967). On average females that nested earlier in the spring moved much farther to subsequent nesting attempts than those nesting later in the season (*Figure 4A*) and moved shorter distances to subsequent nesting attempts as latitude increased (*Figure 4B*). Our dataset of GPS tagged woodcock allowed us to identify discrete nest site locations and subsequent movement patterns for individuals along their migratory paths (*Figure 5*Error! Reference source not found.). The peculiar movement patterns we observed have led us to classify the woodcock as a migratory double breeder (i.e., itinerant breeder). Consistent migration among nesting attempts by our GPS-marked females suggests itinerant breeding is a ubiquitous trait in American Woodcock, and likely plays a critical, but previously under-appreciated role in the species' population ecology.

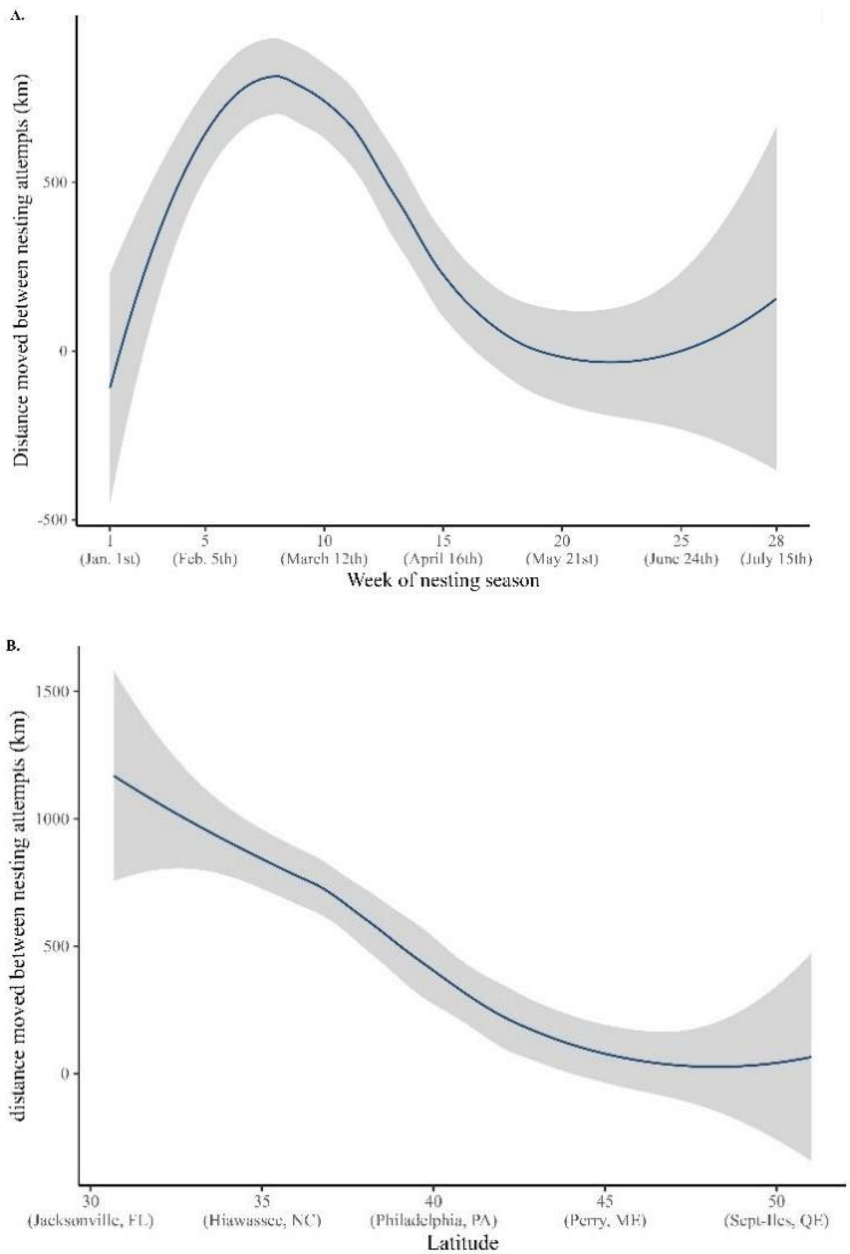

Figure 4. Panel A (top): Smoothed Loess line with 95% confidence bands depicting the moving average of distance moved between nesting attempts, by week of nesting season, for 337 nesting attempts from 154 females tracked between 2019 and 2022. Panel B (bottom): Smoothed Loess line with 95% confidence bands depicting the moving average of distance moved between nesting attempts, by latitude, for 337 nesting attempts from 154 females tracked between 2019 and 2022.

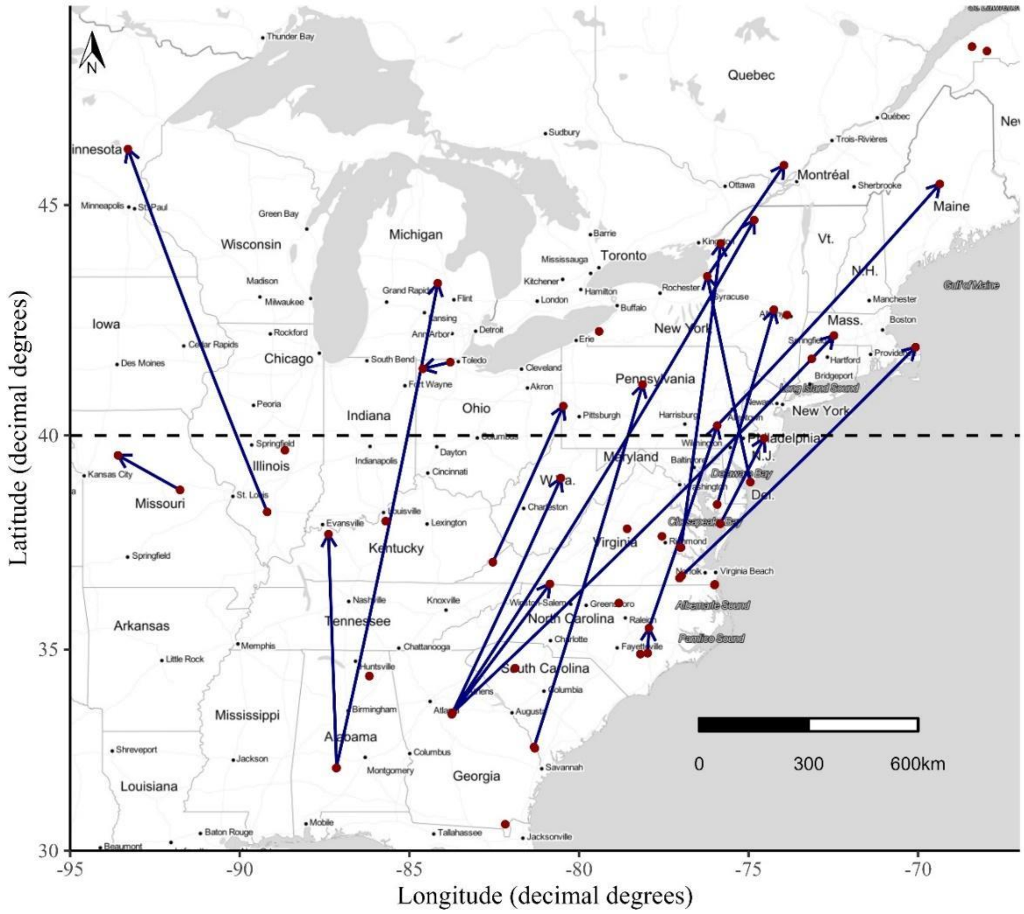

Figure 5. Nest sites (dark red points) connected along individual migratory paths (navy blue lines) for 52 females tracked almost daily from 20 February to 1 June in a given year (2019-2022). Arrow shows the direction of female movement between each nesting attempt. Females that nested once or within 5 km of the original nest site are represented by a single dark red point. The black dashed line at 40 degrees latitude represents the southern extent of the traditional woodcock breeding range.

5. Multi-seasonal species distribution models better facilitate habitat conservation for a migratory bird (Lead: Liam Berigan; *in review at Biological Conservation*)

Abstract: Species distribution models have issues with cross-seasonal transferability when data collected during a single season do not reflect habitat relationships across other seasons. This issue can be addressed using spatial decision support systems, which allow users to incorporate multiple season-specific distribution models into a single tool to facilitate conservation decisions. We demonstrated a potential application of this framework through an analysis of multi-season habitat use for American woodcock in Pennsylvania, USA. We modeled woodcock breeding and migratory habitat distributions in Pennsylvania, USA, using random forest classifiers, and integrated the predictions of both models into a single decision support system using a Shiny application, the Woodcock Priority Area Siting Tool, or W-PAST. The Shiny application accepts user input through breeding and migratory season weights, allowing users to customize the tool based on area-specific management priorities. We found that woodcock have low cross-seasonal transferability between breeding and migratory season models, with Pearson correlations of 0.15 at a pixel-scale and 0.39 at a local management area scale, indicating that conservation of breeding habitat alone is unlikely to result in efficient conservation of migratory habitat for woodcock. Woodcock breeding and migratory habitat is also unevenly distributed at a regional scale, with 3 Pennsylvania ecoregions having low breeding suitability but high migratory suitability. Creating a multi-season distribution model for woodcock management highlighted important migratory areas that may otherwise be overlooked due to a lack of breeding season occupancy, such as urban greenspaces. Flexibility in data sources and ability to compensate for low cross-seasonal transferability in distribution

models make multi-season distribution modeling ideal for the study of birds and other migratory taxa.

6. Adapting hidden Markov models to data from small GPS transmitters for tracking migratory birds (Lead: Liam Berigan; *in prep for submission*)

Abstract: Widespread collection of GPS data from migratory birds necessitates tools for the effective processing and classification of that data. Tools such as hidden Markov models provide opportunities for classifying GPS data, but are designed for regular, high frequency data which is typically not provided by migratory birds. However, the use of additional data streams to fit movement states can assist with fitting cryptic movement states and may assist with fitting movement states with sparse and irregular GPS data. Here we test an approach using a correlated random walk model and additional data streams to fit hidden Markov models to GPS data from bird migrations with American Woodcock as a model system. Our objectives were to determine if the use of additional data streams resulted in an improved capacity to predict migratory states, describe the migratory phenology of woodcock, and characterize long-distance movements by woodcock outside of the migratory season. We found that the inclusion of additional data streams greatly improved the performance of hidden Markov models, although the individual impact of each added data stream was low. Woodcock migratory phenology largely followed prior descriptions, although we observed low incidence of continued migration during the wintering and breeding seasons. We also observed dispersal, foray loops, and summer migrations occurring among woodcock outside of the migratory periods. Despite our progress in applying hidden Markov models to bird data, the complexities required to do so demonstrate how major new developments in the development of movement ecology tools have largely not extended to the modeling of sparse and irregular data generated by avian tracking

studies. New techniques and applications are likely to be necessary to accommodate the accelerating effort to understand bird migration using GPS, Motus, and other technologies.

Work in Progress

1. American Woodcock survival across migratory stages inferred from satellite telemetry data in a continuous-time modeling framework (Lead: Sarah Clements)

Understanding demographic rates, including survival, is fundamental to conservation and management planning for woodcock. However, the birds' variety of behavioral states and the numerous landscapes they use often makes survival highly variable throughout the year (e.g., Sillett & Holmes 2002). With mark-recapture or mark-recovery data only, quantifying survival within seasons or stages of the annual cycle can be difficult for migratory species like woodcock. Satellite telemetry data can give us detailed information about bird movement at a fine temporal scale, but device failure or other technological limitations (Hofman et al. 2019) and presumed device effects on birds (Cleasby et al. 2021) can make it difficult to quantify survival from tracking data. Additionally, although many studies model survival probabilities in discrete time, modeling mortality hazard rates in continuous time may better fit the structure of movement data (Ergon et al. 2018, Rushing 2023). We plan to revisit and expand on questions related to survival explored by Fish (2021) using an updated dataset and a different modeling framework. Our objectives are to (1) quantify mortality hazard rates for woodcock in pre-migration, migration, and post-migration periods; (2) compare mortality hazard rates between spring and fall migration, and (3) evaluate how survival differed among demographic groups and by location.

To improve survival estimates from our woodcock tracking data, we will use behavioral classifications described *above* (Berigan et al. in prep) and a continuous-time multistate model (Rushing 2023) implemented in Stan (Stan Development Team 2023) to estimate state-specific mortality hazard rates for woodcock. The model is still in early development, but preliminary results suggest lower mortality rates during pre-migration and relatively higher mortality rates during migration and post-migration periods. We plan to run the model on both spring and fall migration data, and build upon it to include effects of age, sex, and location of birds. We also hope to derive annual survival probabilities from other available data sources (e.g., banding, parts collection survey, singing ground survey; Saunders et al. 2019) and compare them to seasonal and annual survival probabilities based on our movement data.

2. Habitat selection throughout the full annual cycle (Lead: Liam Berigan)

Bird species frequently select habitat with different characteristics in different seasons, or in different parts of their range (Stanley et al. 2021). Quantifying these differences is especially important for woodcock management, not only to ensure that land managers have access to regionally specific habitat management guidelines, but also to allow managers to differentiate between breeding season and migratory habitat and understand where there are opportunities to manage for both. To this end, we are performing a full annual cycle habitat selection analysis on the woodcock locations collected by the EWMRC. We plan to test multi-scale selection for several habitat characteristics that have been shown to be useful in other woodcock habitat studies (Allen et al. 2020), including landscape composition, configuration, soil moisture, and slope. We will conduct the selection analysis by bird conservation region and season so that we can understand how woodcock habitat relationships change in both space and time, and provide local recommendations for full annual cycle management of woodcock populations. To expand our ecological knowledge of woodcock, we will also examine how the scale of woodcock selection for habitat changes through different stages of the full annual cycle by examining metrics such as home range size and will investigate variation in habitat selection strategies within regional populations. This will be a chapter in Liam Berigan's dissertation (anticipated graduation 2024).

3. Response to light pollution during migration (Lead: Rachel Darling)

There is a growing body of evidence suggesting that light pollution can cause widespread disruption during bird migration, both through local attraction of birds to high intensity light sources (Van Doren et al. 2017) and regional selection of artificially lit areas for migratory stopovers (McLaren et al. 2018). As woodcock are disproportionately the victims of window strikes (Loss et al. 2020), they are believed to be especially vulnerable to light pollution. We leveraged our dataset GPS-tagged woodcock and the New World Atlas of Sky Brightness (Falchi *et al.* 2016 & Falchi *et al.* 2016) to examine the relationship between woodcock migratory stopover selection and night light. We ran step selection functions by migratory season and age-sex class, and compared the approximate level of light each bird encountered as it initiated each stopover with light levels at random steps along the bird's migration trajectory. Preliminary analyses (Figure *6*) show that in the spring, adult males (n = 83) select for night light ($\beta = 0.15 \pm 0.06$, odds ratio of 1.16), and in the fall, young females (n = 35) select for night light ($\beta = 0.18 \pm 0.09$, odds ratio 1.19). All other age-sex class relationships with night light were not significant. Next steps in this analysis include adding covariates, such as landcover, and running step selection functions on within-stopover movements. This will be a chapter in Rachel Darling's dissertation (anticipated graduation 2026).

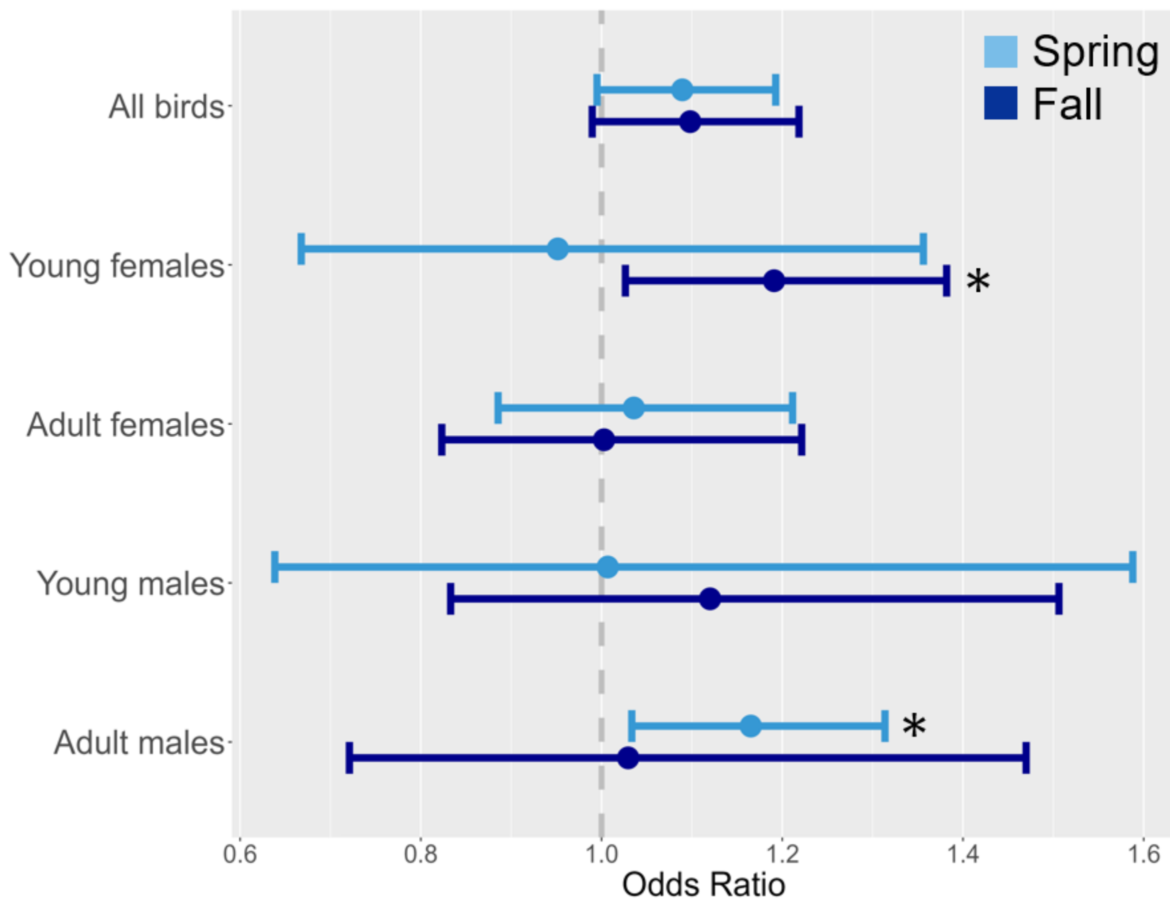

Figure 6. The odds ratios that a woodcock will choose an area with more light over an area with less light, by age-sex class and season. Spring is represented by light blue, fall by dark blue. Asterisk indicates $p < 0.05$.

4. Genomic and isotopic analysis of population connectivity (Lead: Rachel Darling)

Our satellite tracking data has confirmed woodcock migrate between the EMR and CMR (approximately 30% cross management region boundaries during migration). Most of these movements occur between CMR wintering areas and EMR breeding areas, but some woodcock (~4%) also migrate from EMR wintering areas into the CMR to breed. This illustrates lack of strong migratory connectivity within each region, which seems to be supported by our preliminary genomic results, described below.

To expand our analysis of migratory connectivity and to better understand how low connectivity may affect population structure, we will evaluate genomic and stable isotopic signatures from blood and feather samples collected from marked woodcock since the beginning of the project. These data will provide regional markers to identify at a coarse scale the natal origin for each woodcock, and in combination with the project's migratory data, determine the frequency that woodcock return to natal regions, or disperse to others. Our objectives for this work are to 1) conduct a range-wide assessment of population genomic structure for American Woodcock, 2) relate genomic signatures from GPS-marked woodcock to their movements throughout the annual cycle to identify mechanisms governing population structure via migratory connectivity, 3) compare isotopic assignment of GPS-marked woodcock to their migration and dispersal throughout the Eastern and Central Management Regions, and 4) based on results of objectives 1 through 3, evaluate evidence for finer-scale population structure within each management region. This work is supported by a grant from the US Fish and Wildlife Service Webless Migratory Gamebird Research fund.

During spring/summer 2023 we obtained the first results from our population genomic assessment. We've processed 192 genomic samples from woodcock with complete or near-complete migration paths (indicating accurate wintering and summering locations). To conduct these analyses, we first identified single nucleotide polymorphisms (SNPs) within the woodcock genome. SNPs are variants in the nucleotide base pairs of DNA (A, G, T or C) that occur in >1% of a species, and are commonly used to distinguish genetic variability between populations or sub-populations of a species. Based on alignment with its own genome, we were able to isolate 68,067 SNPs from our woodcock samples. A Bayesian clustering analysis was unable to recover any signal of population differentiation from these samples (*Figure 7*), including no differences among birds summering (panel **Error! Reference source not found.**A) or wintering (panel B) in the EMR and the CMR, and no spatial structure in general.

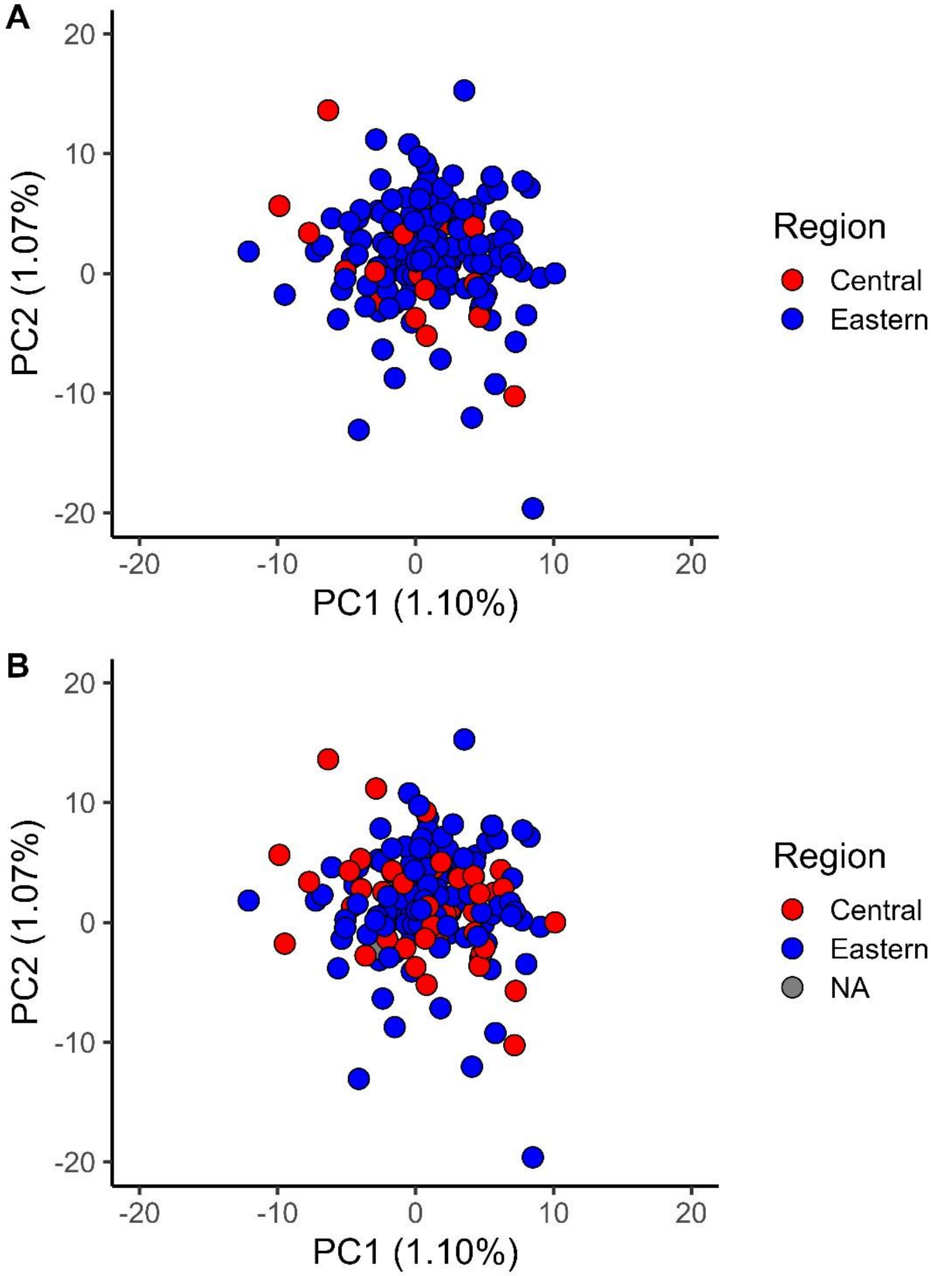

Figure 7. Principal Component Analysis (PCA) results based on (A) summer and (B) winter locations. Locations in the CMR are in red, and locations in the EMR are in blue.

This suggests regular gene flow is producing genetic admixture within the global woodcock population; based on a bird's genomic signature, we can't tell a woodcock breeding in Wisconsin apart from one breeding in Maine. However, at present our sample of woodcock that have migrated into the CMR during the wintering (n=49) and breeding seasons (n=24) is much more limited compared to those migrating into the EMR (n=143 and 168, respectively). Additional sampling of migrant woodcock in the CMR is necessary to bolster sample sizes and improve our inferences, and we plan to accomplish this in the upcoming year through a combination of additional captures in Louisiana, and possibly by sampling woodcock tissue collected via the woodcock wing bee. This will be a chapter in Rachel Darling's dissertation (anticipated graduation 2026).

5. Altitudinal distribution of woodcock flight locations during migration (Lead: Liam Berigan)

In fall 2020, Lotek began to incorporate altitude recorders into all newly-built PinPoint Argos GPS transmitters, which can be used to determine the likely altitude that birds are flying at during migration. Flight altitudes are particularly relevant as low altitudes lead to increased exposure to certain hazards, such as wind turbines and building collisions. To date we've collected >139 suspected night flight locations from tagged woodcock. Our preliminary analysis has shown that flight altitudes are higher during the spring than the fall (Figure *8*Error! Reference source not found.). The most likely reason for a change in flight altitudes would be seasonal differences in the altitude required for favorable winds for migration. We plan to continue this study using a Bayesian analysis to compensate for GPS error and delineate flight and ground locations. We will also look for differences in flight altitudes between sex and age classes, in addition to tracking how flight altitude changes seasonally in response to weather events. This will be a chapter in Liam Berigan's dissertation (anticipated graduation 2024).

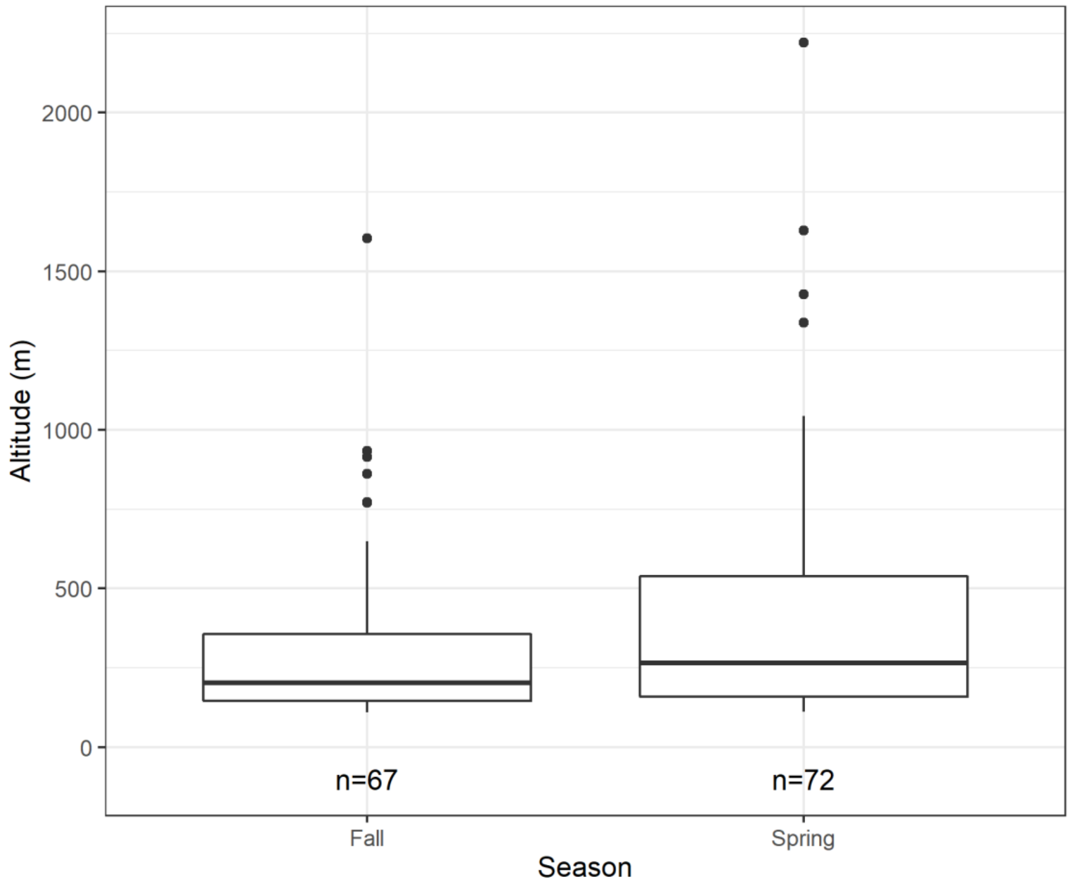

Figure 8. Flight altitude of American Woodcock shifts seasonally, with higher altitudes predominantly recorded during the spring.

6. American Woodcock resource selection in New York State during breeding season (Lead: Kayleigh Filkins)

EWMRC partners from SUNY Brockport and the New York State Department of Environmental Conservation (NYSDEC) are leading a project with a goal of better understanding woodcock resource selection in New York State. The focus of this project is primarily on understanding landscape use during the breeding season, with some consideration given to migratory stopover sites. This analysis uses data from birds that have spent time in New York. Early analysis using a generalized linear model with used and random points as a response variable and percent landcover based on Nature Conservancy Terrestrial Habitat Map shows birds selecting for wet meadow/shrub marsh and against central oak pine, agriculture, northern swamp, northern hardwood conifer, and water (*Figure 9*). Environmental factors such as elevation, canopy cover, distance to water, and yearly weather patterns will be added to this model. Further analysis will use integrated step selection models implemented in the amt package (Signer et al. 2019) in R (R Core Team 2023) to build robust resource selection functions for breeding and migratory movements. We will also calculate home range sizes to better understand the amount of space being used during breeding season (*Figure 10*). These models will be the basis for a woodcock habitat selection and management tool designed to help the NYSDEC with woodcock habitat prioritization. This work will be the basis for Kayleigh Filkins' master's thesis (anticipated graduation 2024).

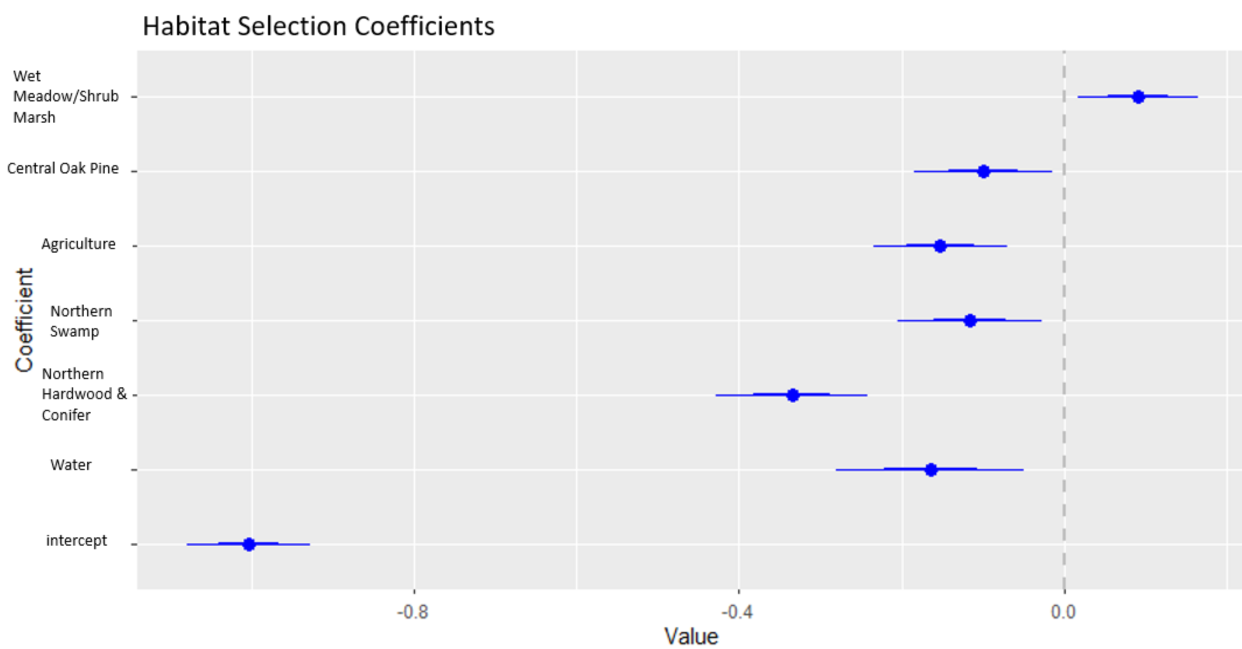

Figure 9. Habitat selection coefficients (with the upper and lower 95th percent confidence interval) of non-migratory American woodcock within New York State + 50 km buffer from 2017 – July 2023.

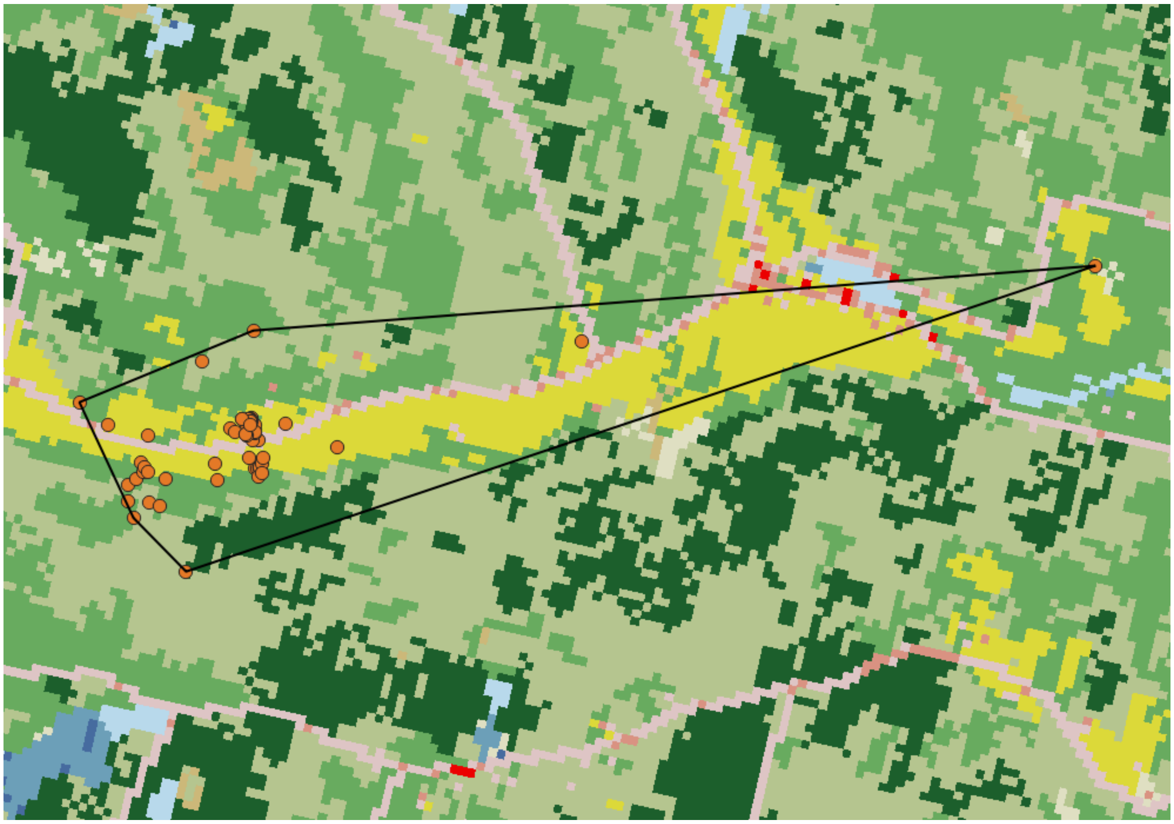

Figure 10. Example of a home range (157 ha) of a breeding American woodcock, using a minimum convex polygon, during the 2022 breeding season in New York, overlaid on the NLCD (2021) dataset (Dewitz 2023).

7. West Virginia Ecoregions Project (Lead: Kylie Brunette)

In April 2023 Erik and Rachel traveled to the Mountain State for a pilot field season, working in collaboration with the West Virginia Division of Natural Resources to conduct a comprehensive study of woodcock spatial ecology in West Virginia. Through a joint effort of Canaan Valley NWR, Old Hemlock Foundation, WVDNR, and UMaine personnel, we captured 31 woodcock and deployed the first 20 GPS tags for this project. Our goal is to mark 20 woodcock in each of West Virginia's 4 ecoregions over a 3-year study period. During 2023 we deployed 10 transmitters in the Allegheny Mountains and 10 in the Western Allegheny Plateau ecoregions, however 6 of the transmitters deployed in the Allegheny Plateau region failed to transmit data, possibly due to manufacturing issues.

This fall, a new M.S. student, Kylie Brunette, began her studies at the University of Maine and will take the lead on coordinating this project going forward. Previous research has focused on northern, high-density areas of the woodcock breeding range, leaving the southern portion of the population largely understudied. West Virginia sits between the wintering grounds to the south and the highly productive northern breeding areas, and the impact of demographic rates in southern breeding areas on the overall population remains unknown. A diverse land use history in the state includes surface mining and agriculture; mine site reclamation and agricultural abandonment generates the early successional habitat used by woodcock. We will investigate differences between these habitat types on woodcock reproductive success in West Virginia, specifically measuring nesting density and daily nest survival rates. We will also investigate woodcock movement throughout the state during both breeding and migratory periods. This research will help us understand the role southern breeding woodcock play in the population dynamics of the species, provide insight into nesting site types and the success rates on those sites, and lead to an interactive tool managers can use to facilitate habitat management decisions for woodcock in West Virginia. This work will be the basis of her master's thesis (anticipated graduation 2026).

8. The Effect of Urbanization on Woodcock Stopover Behavior (Lead: Zoe Pavlik)

Urban landscapes may impact bird species in complex ways, with some species exploiting urban environments, others adapting to them, and others avoiding them (Isaksson 2018). Urban areas have been found to have lower bird species diversity than what would be predicted based on range maps (Aronson et al. 2014). Migration routes of the American woodcock cover large areas of the east coast and include areas with major cities. These migrations include stopovers, which may be affected by urbanization in the surrounding environment. As part of the Undergraduate Honors program at the University of Maine, Zoe Pavlik will explore the effects of urbanization on woodcock stopover, using the percentage of impervious surface within a buffer surrounding the stopover sites as an urbanization metric. National Land Cover Database impervious surface data (Dewitz, 2023) at stopover locations will be compared to migratory step length, stopover duration, and the full migration distance of GPS-marked woodcock. This will form the basis of Zoe Pavlik's undergraduate honors thesis (expected graduation 2024).

Outreach

Our primary means of distributing information is the EWMRC email listserv, which includes representatives from 36 states, provinces, federal agencies, and non-governmental organizations engaged in woodcock conservation. We also use our website, www.woodcockmigration.org, to distribute up-to-date woodcock migration information to any interested parties. Since it was launched, the website has gained a considerable following (>77,000 unique visitors, > 237,000 page views), and we have also incorporated interactive Shiny apps to allow users to interface with our migratory data and hopefully drive more traffic. As we finalize analyses, we will include our results on the website, as well as links to published studies.

Our data have also been incorporated into a number of national databases, including the National Audubon Society's Bird Migration Explorer (explorer.audubon.org), which is an educational resource for learning about North American bird migration, connectivity, and conservation. Additionally, the Cornell Lab of Ornithology has used our data to validate BirdFlow (https://birdflow-science.github.io/), an R package that uses eBird data to predict bird migration. We have contributed data to the Shorebird Science and Conservation Collective, an initiative housed within the Smithsonian's National Zoo and Conservation Biology Institute which coalates and provides shorebird tracking data to conservation practitioners. Through the shorebird Collective, EWMRC data have contributed to conservation projects in Minnesota and the Canadian Maritimes in the last year.

EWMRC personnel have also presented project results in a number of professional and outreach settings, including in 2023 the Maine Chapter of the Ruffed Grouse Society, Downeast Chapter of the Maine Audubon Society, and the University of Saskatchewan, as well as introducing undergraduate students at the University of Maine to woodcock survey and capture methods. Finally, we continue to present our results at wildlife and ornithology conferences, including recent presentations at the American Ornithological Society's annual meeting in August 2023 and the Maine Chapter of the Wildlife Society meeting in December 2023. A full list of outreach and professional presentations is provided below.

EWMRC Output to Date

Peer-reviewed publications

Blomberg, E. J., and 25 coauthors. 2023. The American Woodcock Singing Ground Survey largely conforms to the phenology of male woodcock migration. Journal of Wildlife Management. https://doi.org/10.1002/jwmg.22488

Fish, A. C. and 27 coauthors. *In revision*. American woodcock (*Scolopax minor*) fall and spring migration phenology in Eastern North America: implications for hunting season timing. Journal of Wildlife Management.

Clements, S., and 26 coauthors**.** *In revision*. Lack of evidence for discrete migration strategies in American woodcock suggests potential for species' resilience. Ornithology.

Berigan, L., A. C. Fish, A. Roth, L. Williams, K. Duren, S. Bearer, and E. J. Blomberg. *In review.* Joint life-stage-specific distribution models better facilitate habitat conservation for a short distance migratory bird. Biological Conservation.

Slezak, C., and 26 coauthors. In review. Unconventional life-history in a migratory shorebird: desegregating reproduction and migration. Proceedings of the Royal Society of London B – Biological Sciences.

Professional presentations

Blomberg, E. The American Woodcock signing ground survey largely conforms to the phenology of male woodcock migration. American Ornithological Society and Canadian Society of Ornithologists Joint Conference, London, Ontario, Canada, August 2023.

Blomberg, E. The American Woodcock signing ground survey largely conforms to the phenology of male woodcock migration. Maine State Chapter of the Wildlife Society Fall Meeting, Orono, Maine. December 2023.

Darling, R. American woodcock select for areas of artificial light at night during migration. American Ornithological Society and Canadian Society of Ornithologists Joint Conference, London, Ontario, Canada, August 2023. (poster).

Clements, S. Lack of discrete migration strategies in American Woodcock suggests potential for species resiliency. American Ornithological Society and Canadian Society of Ornithologists Joint Conference, London, Ontario, Canada, August 2023. (poster).

Berigan, L. Adapting hidden Markov movement models to the study of migration by small-bodied birds. American Ornithological Society and Canadian Society of Ornithologists Joint Conference, London, Ontario, Canada, August 2023.

Berigan, L. Using joint life-stage-specific species distribution models to facilitate habitat conservation for American woodcock. Maine Chapter of the Wildlife Society Annual Fall Meeting, December 2022.

Berigan, L. Revisiting the role of stopover when assessing migratory connectivity: an American Woodcock case study. North American Ornithological Congress, Puerto Rico, 2022.

Berigan, L. Site prioritization for American Woodcock management by comparing breeding and migratory habitat distribution models. The Wildlife Society Annual Conference, 2021

Fish, A. Lower than expected migratory connectivity of American woodcock (Scolopax minor) in Eastern North America. The Wildlife Society Annual Conference, 2019

Fish, A. Migratory ecology of American Woodcock (Scolopax minor) in eastern North America. American Ornithological Society Annual Conference, June 2019.

Outreach presentations:

- Central Maine Chapter of the Ruffed Grouse Society. Brewer, ME, November 2023. Presented by E. Blomberg.
- Maine Audubon Fields Pond Nature Center. Orland, ME, April 2023. Presented by E. Blomberg
- Berigan LA, Filiberti E. 2023. *Migratory Marvels: Understanding Woodcock and Goldenwinged Warbler Migration.* [Oral presentation] Downeast Audubon, Ellsworth ME.
- Berigan LA. 2022. *Meet the Timberdoodle*! [Oral presentation] Friends of Missisquoi National Wildlife Refuge & Green Mountain Audubon Society, Swanton VT.
- Berigan LA. 2022. *What can woodcock teach us about bird migration?* [Oral presentation] Harris Center for Conservation Education, Hancock NH.

- Ruffed Grouse Society National Organization, web-presentation by E. Blomberg, August 2022.
- North American Versatile Hunting Dog Association National Meeting. Portland, ME, January 2020.

Press coverage

- Project Upland magazine profiled our research as part of a profile article on American Woodcock Migration. https://projectupland.com/woodcock-hunting/understanding-the-fall-woodcock-migration/. October 2023.
- E. Blomberg was interviewed and EWMRC was featured in *Project Upland Magazine*, Spring 2023 issue.
- Project Upland magazine profiled EWMRC research as part of a species' profile article. https://projectupland.com/woodcock-hunting/unusual-facts-about-american-woodcock/. August 2022.
- E. Blomberg was interviewed for the web podcast *Her Upland* to discuss EWMRC research. https://projectupland.com. July 2021.
- The Canadian Broadcast Company (CBC) featured out woodcock migration research. September 2020.
- E Blomberg was interviewed for the web podcast *Project Upland* to discuss EWMRC research. https://projectupland.com. January 2019.

Awards

- Wildlife Restoration Award – The Wildlife Society. This award was presented to the Eastern Woodcock Migration Research Cooperative for significant contributions to wildlife conservation stemming from use of Federal Aid in Wildlife Restoration funds. November 2021.

Project Partners

Alabama Department of Conservation and Natural Resources

American Woodcock Society

Association des Savaginiers du Saguenay-Lac-St-Jean

Atlantic Flyway Council

Audubon Vermont

Canaan Valley National Wildlife Refuge

Club des Becassiers du Quebec

Silvio O. Conte National Wildlife Refuge

Environment and Climate Change Canada

Florida Fish and Wildlife Conservation Commission

Friends of the 500th

Friends of Missisquoi National Wildlife Refuge

Georgia Department of Natural Resources

Louisiana Department of Wildlife and Fisheries

Maine Department of Inland Fisheries and Wildlife

Maryland Department of Natural Resources

Missisquoi National Wildlife Refuge

Moosehorn National Wildlife Refuge

The Nature Conservancy in Vermont

New Jersey Department of Environmental Protection

New York Department of Environmental Conservation

North Carolina Wildlife Resources Commission

Old Hemlock Foundation

Pennsylvania Game Commission

Rhode Island Department of Environmental Management

Ruffed Grouse Society

Silvio O. Conte National Wildlife Refuge

State University of New York - Brockport

State University of New York - Cobleskill

South Carolina Department of Natural Resources

US Forest Service

USFWS National Wildlife Refuge System

USFWS Webless Migratory Game Bird Research Program

USFWS Office of Migratory Birds

USGS - Patuxent Wildlife Research Center

University of Maine

University of Rhode Island

Vermont Fish & Wildlife Department

Virginia Department of Wildlife Resources

West Virginia Division of Natural Resources

West Virginia Highlands Conservancy

Wildlife Management Institute

Wildlife and Sport Fish Restoration Program

Woodcock Conservation Society

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Appendices

Additional Tables

Table A1. American Woodcock captured and tagged with satellite GPS transmitters in each state/province collaborating in the Eastern Woodcock Migration Research Cooperative, summarized by year, age, and sex.

		Male			Female			Unknown	Total
State	**Year**	**Young**	**Adult**	**Unk**	**Young**	**Adult**	**Unk**	**Unk**	
Alabama	*2020*	1	2		2	2			7
	2021		2		2	2			6
	2022	5	2	1	1	1			10
Florida	*2021*	1	3		1				5
	2022	2	4						6
Georgia	*2020*	3	3		1	5			12
	2021	1	3		2	5			11
Louisiana	*2022*	4	4		3	4			15
	2023	4	11		1	1			17
Maine	*2017*	4				2			6
	2018	1	1		3	2			7
	2020	1	2			3			6
Maryland	*2018*		1		3				4
	2019		3		5	2			10
	2020	1	3		4	1			9
	2021	3	3		1	1			8

State	Year	Male			Female			Unknown	Total
		Young	Adult	Unk	Young	Adult	Unk	Unk	
New Jersey	*2018*	7			8				15
	2019	8			9				17
New York	*2018*	4	1		1	3			9
	2019	4	6		11	9			30
	2022				5	5			10
	2023	4	2	1	2	3		1	13
North Carolina	*2019*	2	2			2			6
	2020	7	1		4	3			15
	2021	6	1		1	2			10
	2022	5	2		1	7			15
Nova Scotia	*2019*	3			4				7
	2022	4	1						5
Ontario	*2018*		1			1			2
	2019	1			1	1			3
Pennsylvania	*2018*	1	4		3	4			12
	2019	3	1		1	7			12
	2020	3	2		1	7			13
	2021	5	2		2	3			12
Quebec	*2018*	2			2	1			5
	2019	5			2	3			10
	2020	2	1		1	3			7
	2021				2	2			4

State	Year	Male			Female			Unknown	Total
		Young	Adult	Unk	Young	Adult	Unk	Unk	
Quebec	*2022*	2			1				3
Rhode Island	*2018*		12			3			15
	2019		12			3			15
	2020				7	7	3		17
	2021				3	12			15
South Carolina	*2019*	2	1		4	2			9
	2020	2	3		2	1			8
	2021	2	4		1				7
	2022						1		1
	2023						1		1
Virginia	*2018*		6		2	1			9
	2019	10	9		11	13		3	46
	2020	15	5	1	7	16			44
	2021		1		1	2	1	4	9
	2022						2		2
Vermont	*2020*	8	5		3	2			18
	2021	3	1		2	4			10
	2022		2		1	3	1		7
	2023		1						1
West Virginia	*2019*	2	1		1				4
	2020				1				1

		Male			Female			Unknown	Total
State	**Year**	**Young**	**Adult**	**Unk**	**Young**	**Adult**	**Unk**	**Unk**	
West Virginia	*2023*	5	13		1	2			21
Wisconsin	*2023*	1			1				2
Total		**159**	**150**	**3**	**139**	**168**	**9**	**8**	**636**

Table A2. Number of attempted and complete migratory movements by GPS-tagged American Woodcock by season from Fall 2017 through Spring 2022. Complete migratory movements are a result of actual migratory completion as described in Transmitter Schedules *above*; in some instances, tag battery failure occurred before completion could be confirmed.

	Migratory movements	
Season	**Attempted**	**Complete**
Fall 2017	6	3
Fall 2018	47	41
Spring 2019	55	48
Fall 2019	83	62*
Spring 2020	84	61*
Fall 2020	64	46*
Spring 2021	83	53*
Summer 2021	2	2
Fall 2021	37	29*
Spring 2022	76	38*
Fall 2022	21	20
Spring 2023	16	14

* Due to changes made in 2023 to the method of calculating complete migratory paths, these numbers are reduced compared to previous annual reports.

Table A3. Migration initiation and termination dates for American Woodcock tagged with satellite GPS transmitters in the Eastern Management Region from Fall 2018 through Spring 2023.

	n	Mean Mig. Initiation	First Mig. Initiation	Last Mig. Initiation	Mean Mig. Termination	First Mig. Termination	Last Mig. Termination
Fall							
2018	38	11/7/2018	10/12/2018	1/1/2019	12/3/2018	10/28/2018	2/3/2019
2019	74	11/11/2019	10/12/2019	12/13/2019	12/2/2019	10/20/2019	1/29/2020
2020	59	10/28/2020	8/3/2020	12/15/2020	11/30/2020	10/30/2020	1/12/2021
2021	17	10/31/2021	8/31/2021	1/12/2022	11/16/2021	10/25/2021	12/10/2021
2022	22	11/3/2022	10/2/2022	11/23/2022	11/26/2022	11/4/2022	12/12/2022
Spring							
2019	42	3/10/2019	1/26/2019	3/29/2019	4/19/2019	2/8/2019	7/14/2019
2020	55	3/6/2020	2/3/2020	5/4/2020	4/14/2020	2/11/2020	7/28/2020
2021	76	2/28/2021	1/14/2021	4/23/2021	4/2/2021	3/2/2021	5/18/2021
2022	53	2/26/2022	1/19/2022	4/26/2022	4/18/2022	2/21/2022	6/7/2022
2023	16	2/22/2023	2/1/2023	4/5/2023	4/15/2023	3/20/2023	5/9/2023

Table A4. Migration records of GPS-tagged American Woodcock from the migratory seasons of Fall 2022 (September 1st, 2022 – January 31st, 2023) and Spring 2023 (February 1st, 2023 - May 31st, 2023).

Bird ID	Capture Date	Sex	Age at Capture[a]	No. Loc[b]	Location of Capture[c]
Fall 2022					
Nova Scotia					
NS-2022-07*	10/4/2022	M	HY	82	Pleasant Valley
NS-2022-08	10/5/2022	M	HY	70	Pleasant Valley
NS-2022-09	10/5/2022	M	AHY	74	Pleasant Valley
NS-2022-10*	10/6/2022	M	HY	75	Pleasant Valley
NS-2022-11	10/7/2022	M	HY	24	Pleasant Valley
Quebec					
QUE-2022-27	9/26/2022	M	HY	65	Saguenay
QUE-2022-28	9/26/2022	F	HY	64	Saguenay
QUE-2022-29	9/26/2022	M	HY	65	Saguenay
Vermont					
VT-2022-29*	10/17/2022	M	AHY	64	Nulhegan
VT-2022-30*	10/21/2022	F	AHY	68	Buckner
VT-2022-31*	10/18/2022	M	AHY	74	Nulhegan
VT-2022-32	10/17/2022	F	Unk	40	Nulhegan
VT-2022-33*	10/18/2022	F	AHY	69	Nulhegan
VT-2022-34*	10/21/2022	F	AHY	59	Buckner
VT-2022-35*	10/21/2022	F	HY	68	Buckner

Bird ID	Capture Date	Sex	Age at Capture[a]	No. Loc[b]	Location of Capture[c]
Spring 2023					
Louisiana					
LA-2023-17	1/25/2023	M	SY	57	Bodcau
LA-2023-18	1/25/2023	M	SY	37	Bodcau
LA-2023-19	1/25/2023	M	SY	37	Bodcau
LA-2023-20	1/25/2023	F	AHY	37	Bodcau
LA-2023-21	1/25/2023	M	SY	28	Sage
LA-2023-22	1/25/2023	M	SY	54	Sage
LA-2023-23	1/25/2023	M	AHY	37	Sage
LA-2023-24	1/25/2023	M	AHY	12	Sage
LA-2023-25	1/26/2023	M	SY	55	Deridder
LA-2023-26	1/25/2023	M	AHY	47	Sage
LA-2023-27	1/26/2023	M	SY	0	Deridder
LA-2023-28	1/25/2023	M	AHY	5	Sage
LA-2023-29	1/26/2023	M	SY	21	Deridder
LA-2023-30	1/26/2023	M	SY	21	Deridder
LA-2023-31	1/26/2023	M	SY	32	Deridder
LA-2023-32	1/31/2023	F	SY	29	Bodcau
LA-2023-33	2/16/2023	M	SY	64	Deridder
New York					
NY-2023-48	5/2/2023	F	SY	40	Tioughnioga
NY-2023-49	4/20/2023	F	ASY	50	Happy Valley
NY-2023-50	5/9/2023	M	SY	47	Burnt-Rossman
NY-2023-51	5/12/2023	M	ASY	41	Birdseye

Bird ID	Capture Date	Sex	Age at Capture[a]	No. Loc[b]	Location of Capture[c]
NY-2023-52	5/15/2023	M	ASY	31	Three Mile Bay
NY-2023-53	5/18/2023	M	NA	35	Finger Lakes
NY-2023-54	5/18/2023	F	SY	8	Albany
NY-2023-55	5/18/2023	F	ASY	17	Albany
NY-2023-56	6/1/2023	F	ASY	31	Finger Lakes
NY-2023-57	6/6/2023	M	SY	55	Ashland
Nova Scotia					
NS-2022-07	10/4/2022	M	HY	12	Pleasant Valley
NS-2022-10	10/6/2022	M	HY	8	Pleasant Valley
South Carolina					
SC-2023-26	3/31/2023	F		36	Draper
Vermont					
VT-2022-29	10/17/2022	M	AHY	6	Nulhegan
VT-2022-30	10/21/2022	F	AHY	13	Buckner
VT-2022-31	10/18/2022	M	AHY	11	Nulhegan
VT-2022-33	10/18/2022	F	AHY	16	Nulhegan
VT-2022-34	10/21/2022	F	AHY	6	Buckner
VT-2022-35	10/21/2022	F	HY	62	Buckner
VT-2023-36	5/29/2023	M	ASY	5	Buckner
Wisconsin					
WI-2023-01	4/15/2023	F	SY	46	Buenavis

Bird ID	Capture Date	Sex	Age at Capture[a]	No. Loc[b]	Location of Capture[c]
WI-2023-02	4/18/2023	M	SY	38	Buenavis
West Virginia					
WV-2023-06	4/24/2023	M	ASY	34	Canaan
WV-2023-07	4/25/2023	M	ASY	35	Canaan
WV-2023-08	4/25/2023	M	SY	0	Canaan
WV-2023-09	4/26/2023	M	ASY	40	Canaan
WV-2023-10	4/26/2023	M	ASY	2	Canaan
WV-2023-11	4/26/2023	M	ASY	2	Canaan
WV-2023-12	4/26/2023	M	SY	6	Canaan
WV-2023-13	4/27/2023	M	ASY	20	Little Indian Creek
WV-2023-14	4/27/2023	M	ASY	0	Little Indian Creek
WV-2023-15	4/27/2023	M	ASY	0	Little Indian Creek
WV-2023-16	4/27/2023	M	SY	0	Little Indian Creek
WV-2023-17	4/27/2023	M	ASY	0	Little Indian Creek
WV-2023-18	4/28/2023	F	SY	40	Little Indian Creek
WV-2023-19	4/28/2023	M	ASY	1	Little Indian Creek
WV-2023-20	4/28/2023	F	ASY	38	Little Indian Creek
WV-2023-21	4/28/2023	M	SY	0	Little Indian Creek
WV-2023-22	4/28/2023	M	ASY	0	Little Indian Creek
WV-2023-23	5/17/2023	F	ASY	31	Canaan
WV-2023-24	5/17/2023	M	SY	26	Canaan
WV-2023-25	5/18/2023	M	ASY	20	Canaan

[a]Age at capture reflects whether the bird was in its first molt cycle (HY or SY) or had adult plumage (AHY or ASY). [b]The number of GPS locations that each bird recorded during that

migratory season. Certain birds may record less or more points than others, depending on the programmed duty cycle, size of the GPS battery, and occasional mortality during GPS tracking. Bird IDs with asterisks (*) successfully transmitted locations in a subsequent season. [c] Further details names of locations can be found in EWMRC shared google drive, “American Woodcock Migration Project Resources” > folder American Woodcock Data > Excel file AMWO_GPS_Inventory, sheet Deployment_Site_Inventory.

Additional Figures: GPS locations by deployment state

Figures A1 – A9. Maps showing American Woodcock movements in Fall 2022 and Spring 2023, broken out by the state or province in which each bird was originally captured. White points represent GPS locations and each colored path represents an individual bird.

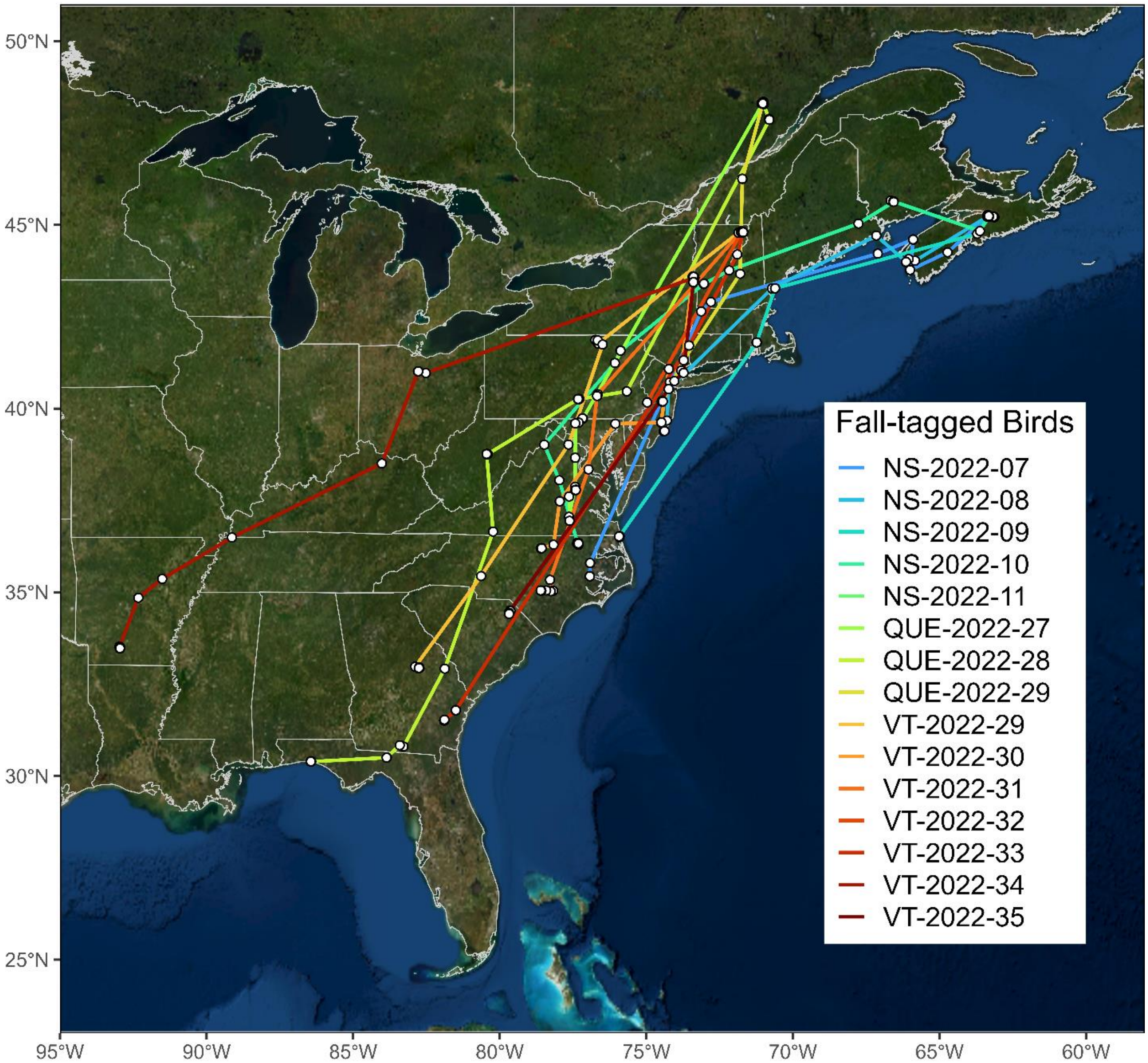

Figure A1. All fall migratory movements from woodcock tagged in Fall 2022.

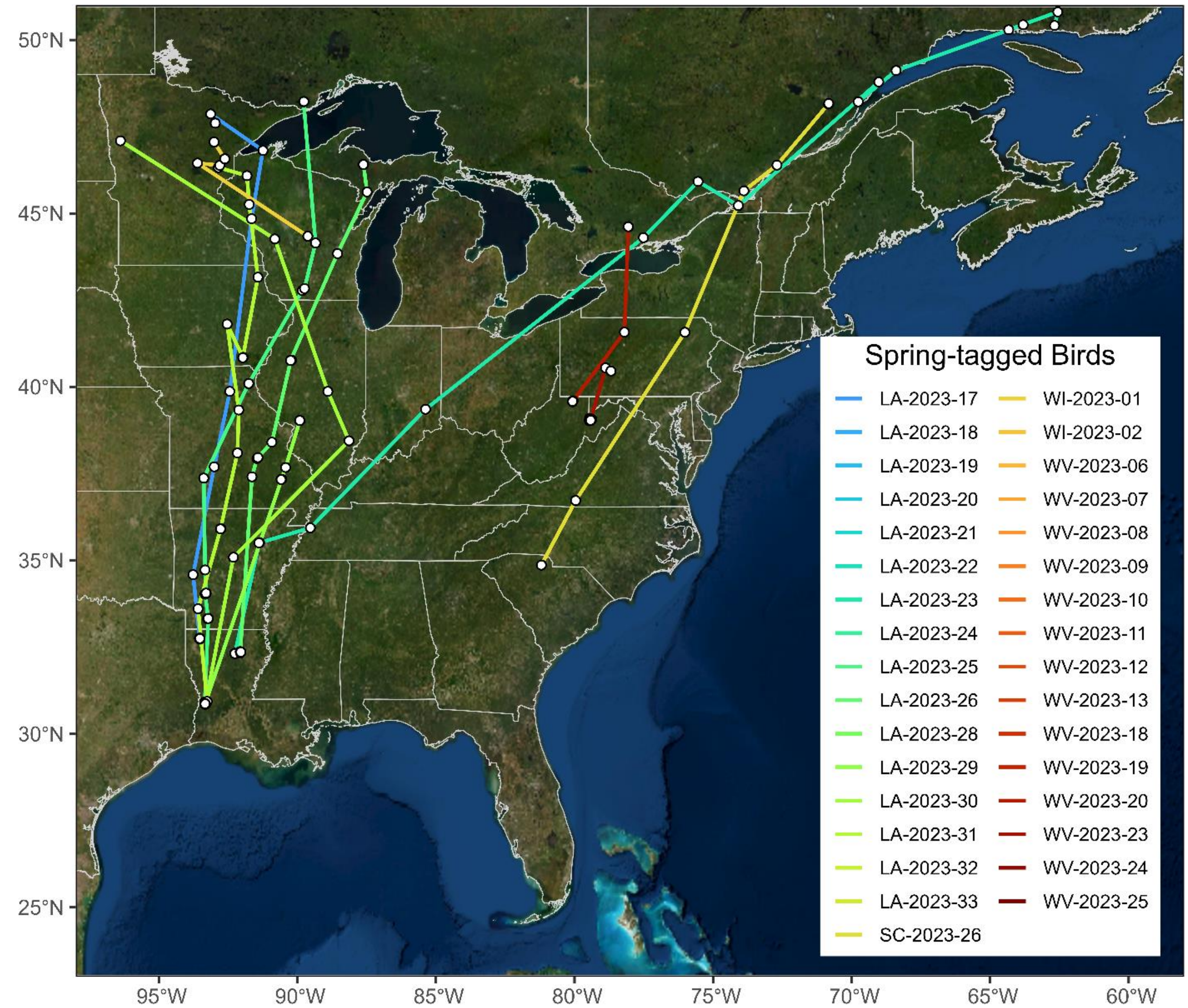

Figure A2. All spring migratory movements from tagged woodcock in Spring 2023.

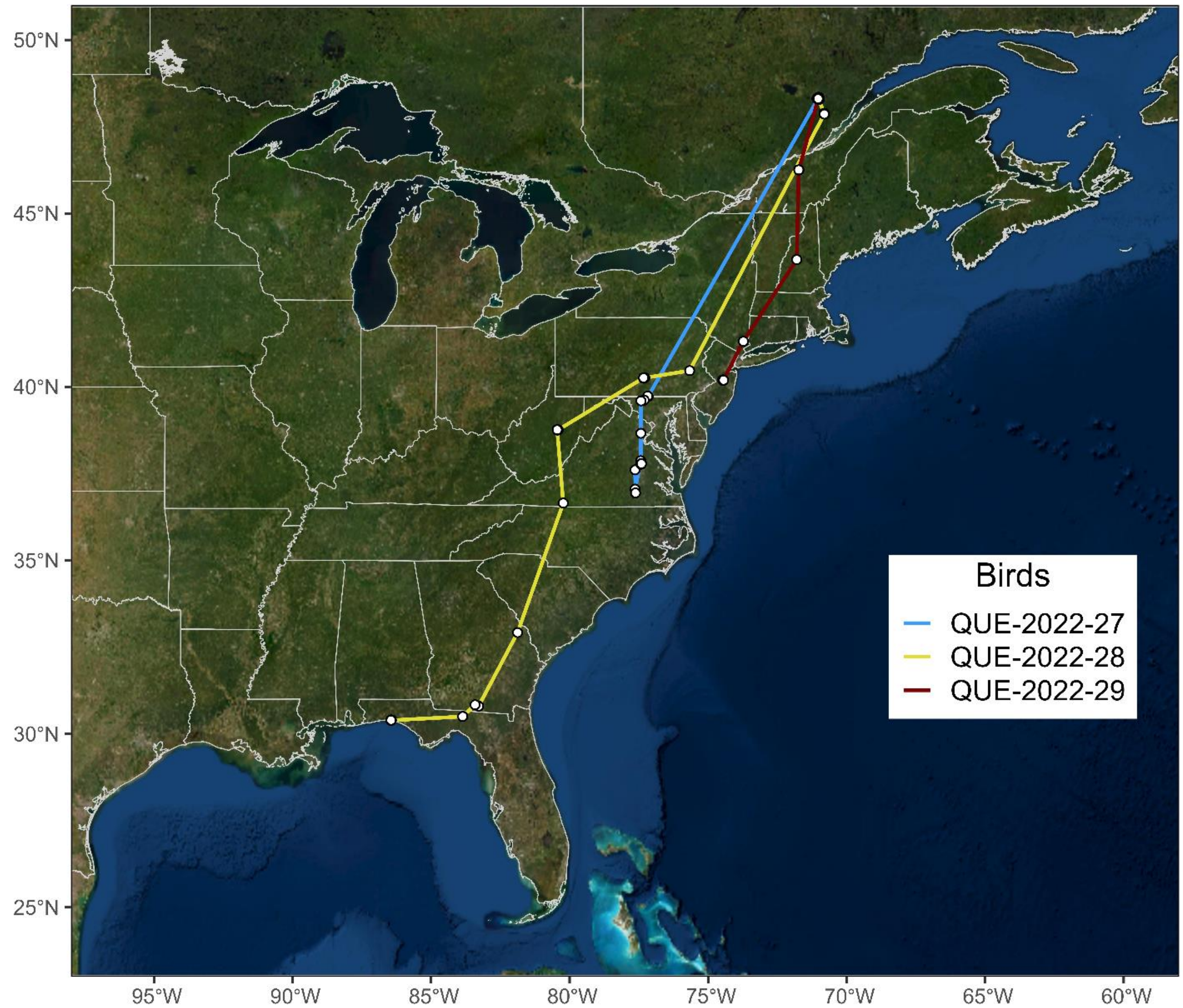

Figure A3. All movements of woodcock tagged in Quebec in Fall 2022.

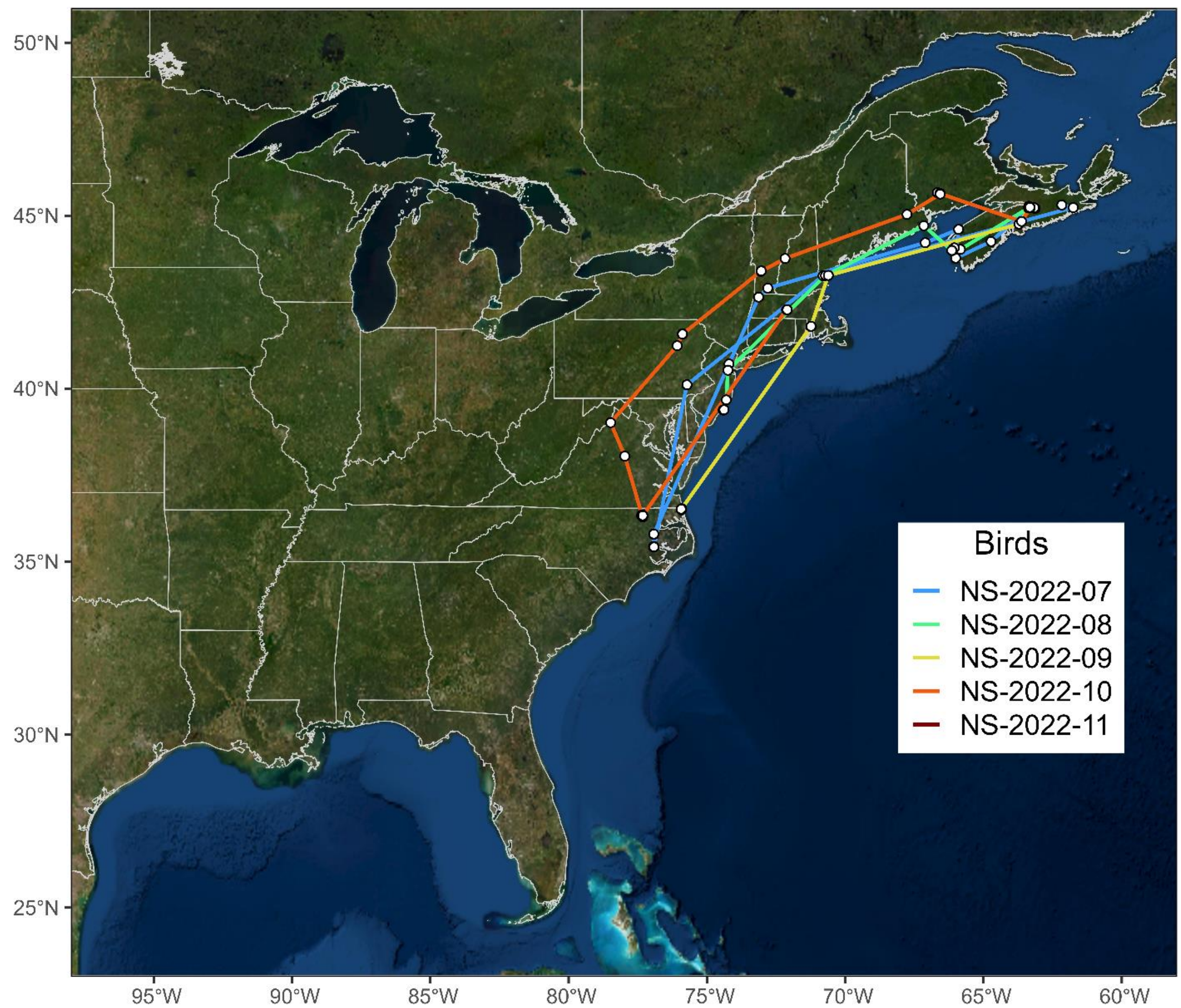

Figure A4. All movements of woodcock tagged in Nova Scotia in Fall 2022.

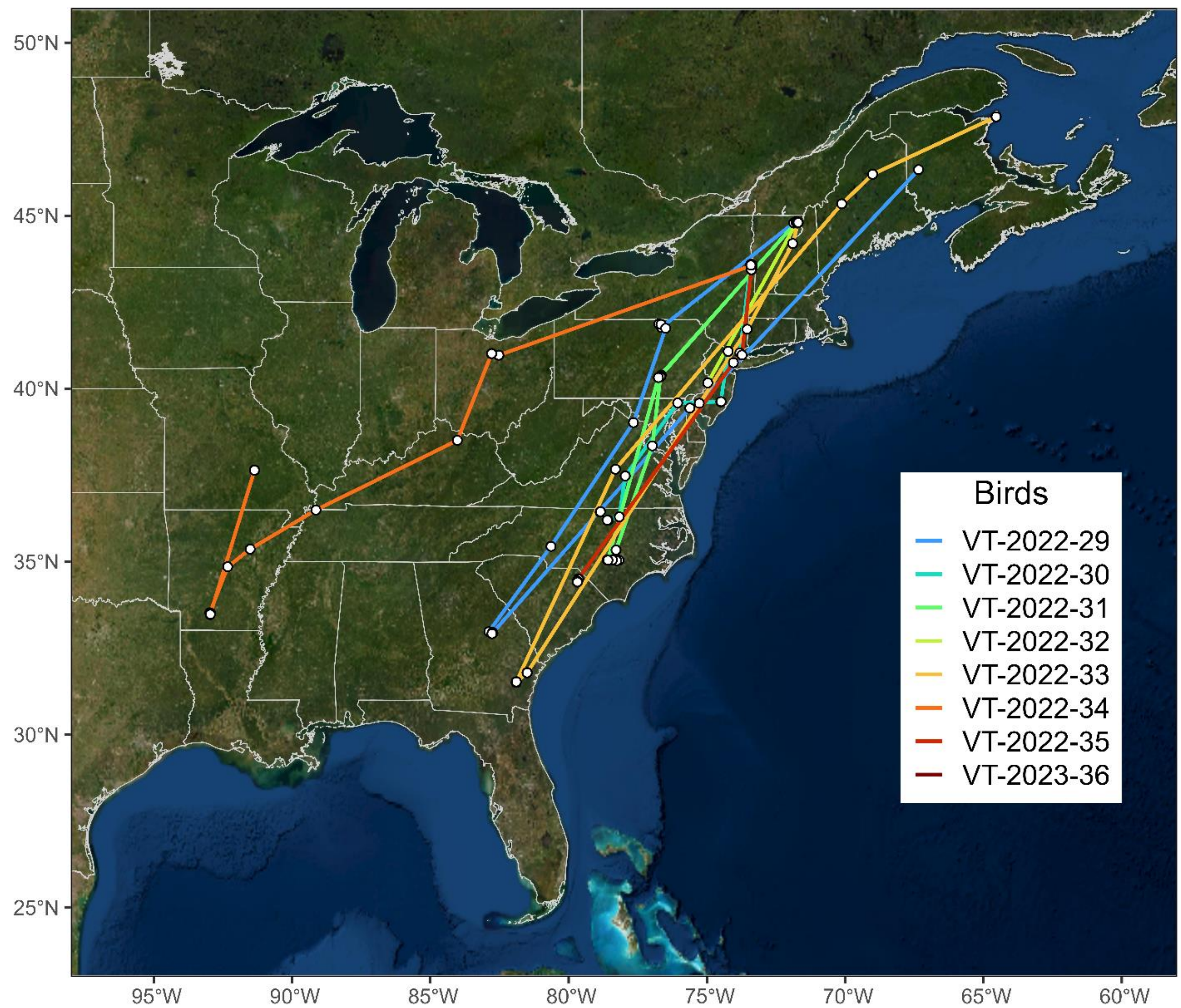

Figure A5. All movements of woodcock tagged in Vermont in Fall 2022, and one bird tagged in Spring 2023.

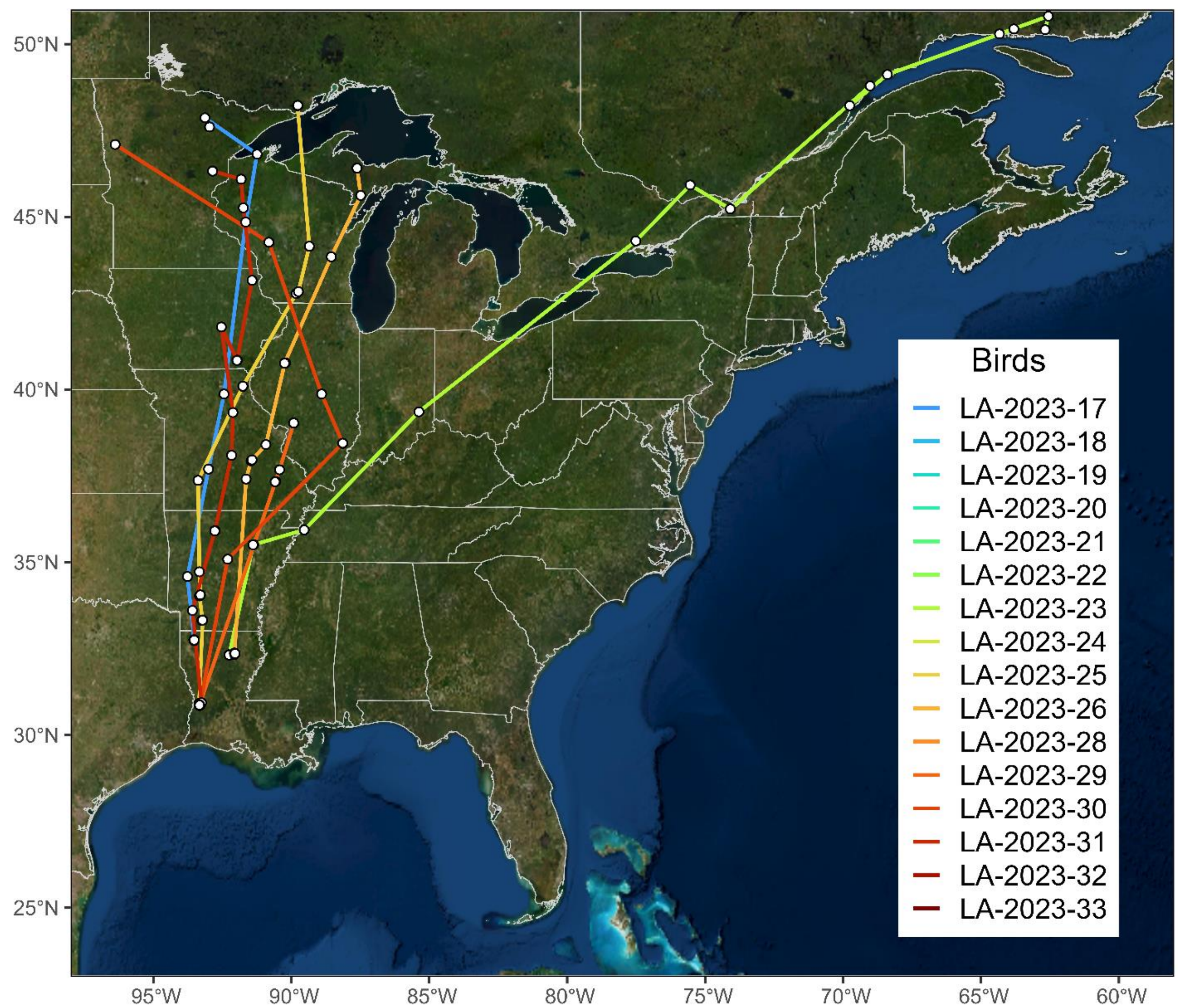

Figure A6. All movements of woodcock tagged in Louisiana in Spring 2023.

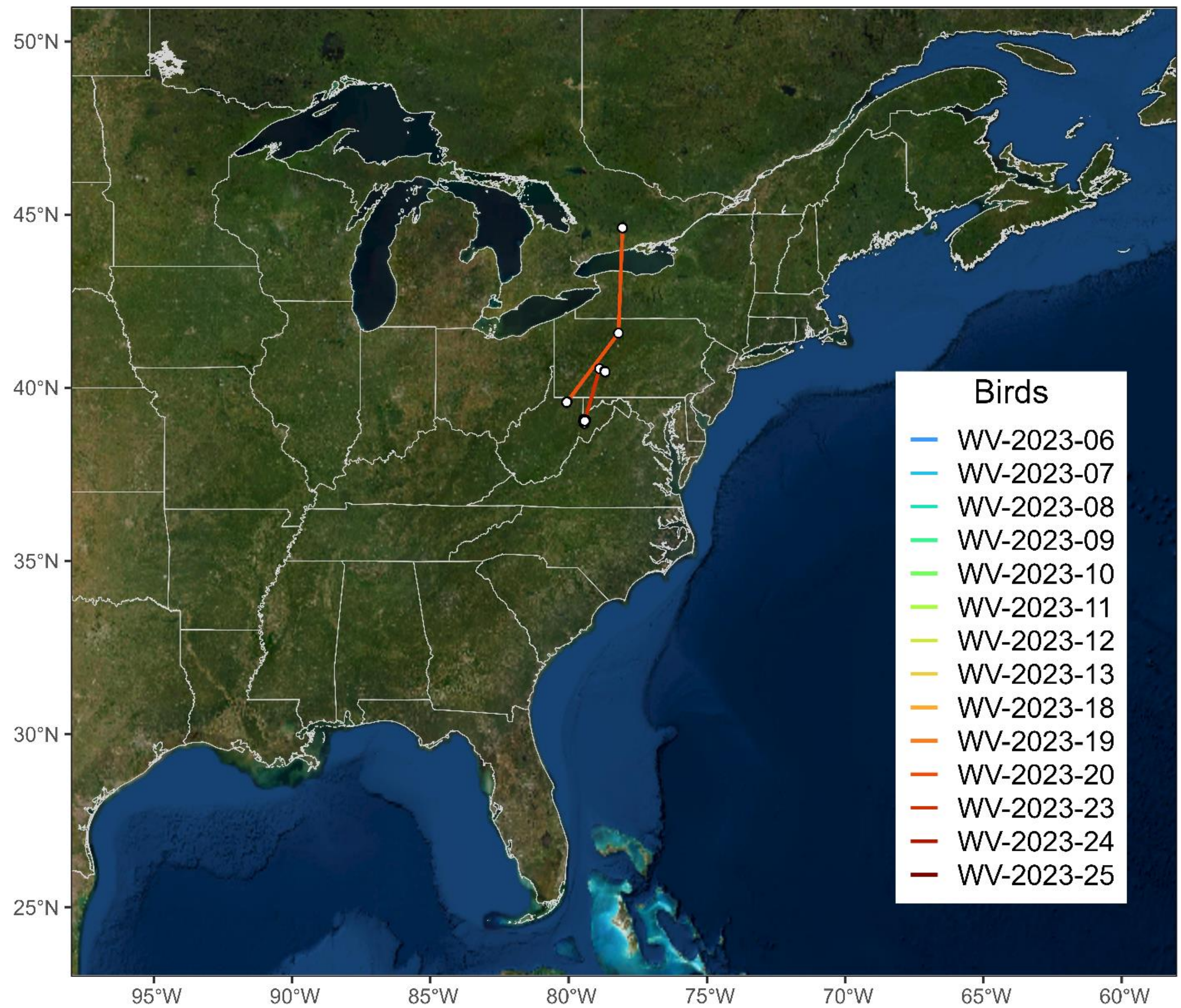

Figure A7. All movements of woodcock tagged in West Virginia in Spring 2023. Most did not move from their tagging locations, as they were tagged during the breeding season. Their tags will come online again briefly in February 2024, and then again in mid-April 2024.

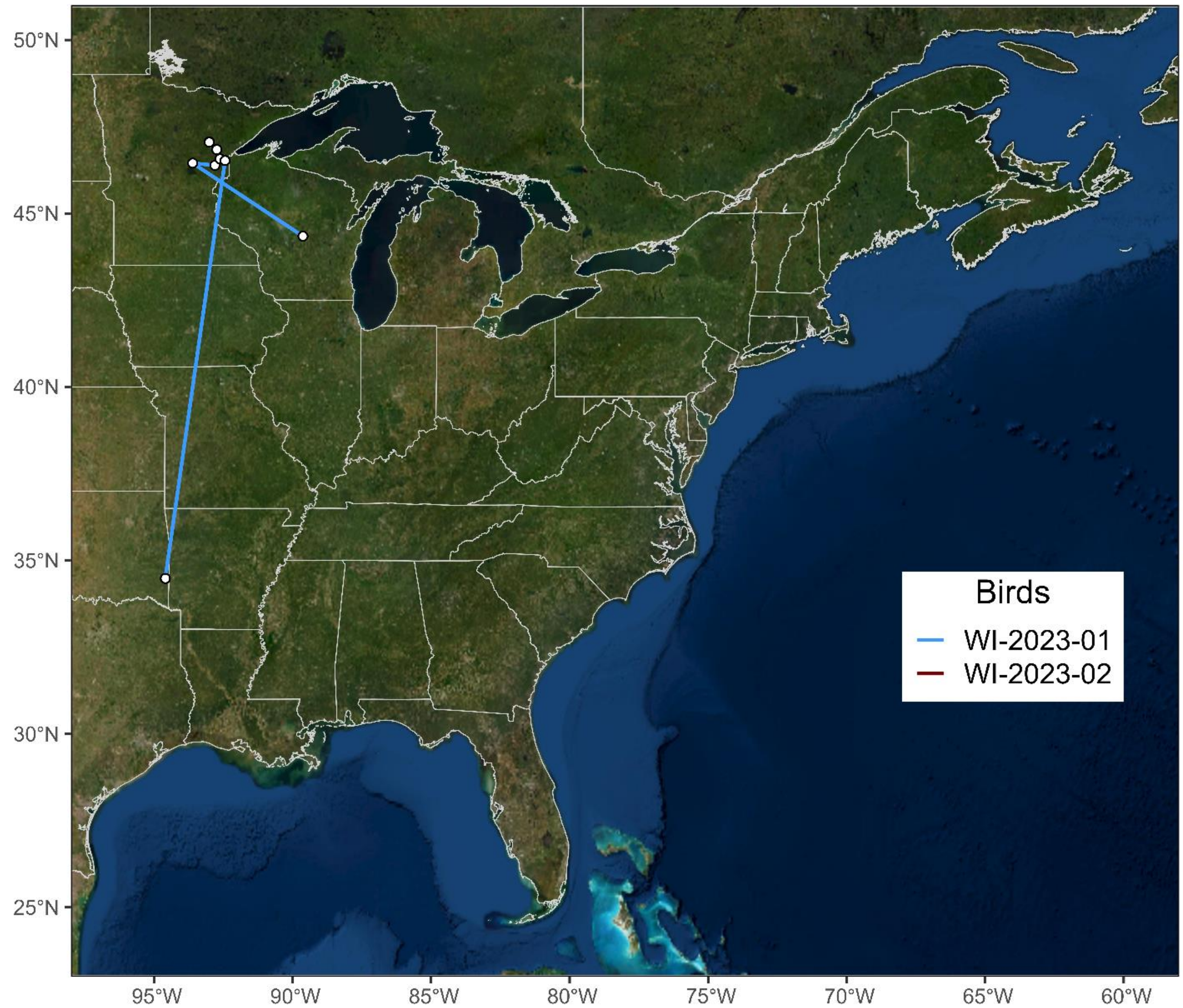

Figure A8. All movements of woodcock tagged in Wisconsin in Spring 2023. WI-2023-02 did not move from his tagging location in central Wisconsin, and thus is obscured by WI-2023-01.

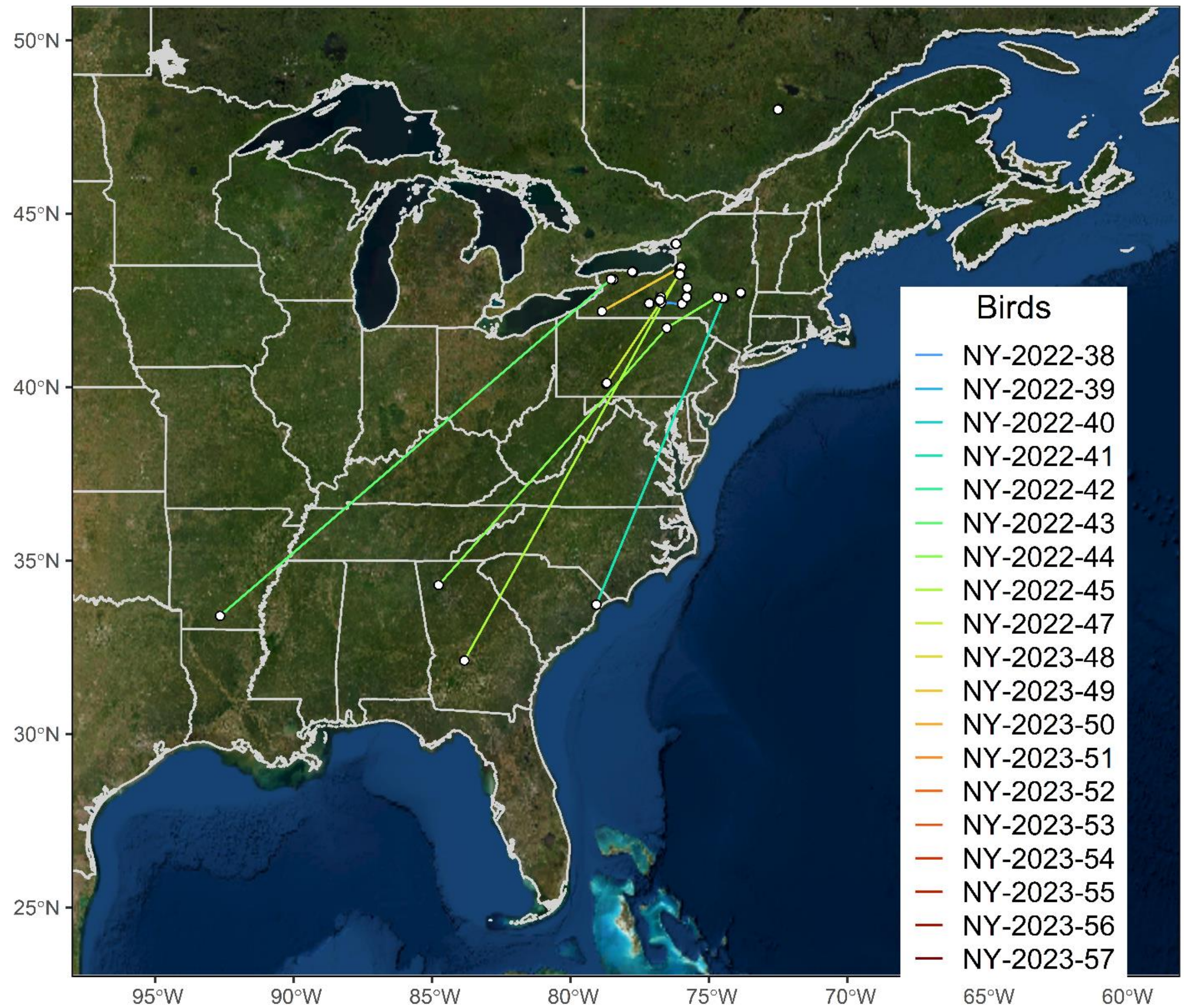

Figure A9. Fall 2022 migratory movements from New York birds tagged in Spring 2022, and locations of birds tagged in New York in Spring 2023. Similar to West Virginia Spring 2023 deployments, New York Spring 2023 tags will come online again briefly in February 2024, and then again in mid-May 2024.