LANDSCAPE USE AND RESOURCE SELECTION DURING THE BREEDING SEASON AND MIGRATION FOR AMERICAN WOODCOCK (*SCOLOPAX MINOR*) IN NEW YORK STATE

by

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Abstract

Globally, bird populations have declined at a rate of 29% in the last 50 years, and shorebirds have some of the fastest rates of decline of any species group (Rosenberg 2019). Among shorebirds, the American woodcock (*Scolopax minor*) has been showing a steady population declines over the past 50 years. One of the leading causes of population declines experienced by woodcock, and other early successional species, is the loss and fragmentation of habitat. I used woodcock location data from GPS transmitters to understand how woodcock used landscapes within New York State during the breeding season and fall and spring migrations. I used a mixed effect generalized linear model to describe woodcock resource selection during the breeding season, utilizing a layer digitized from aerial imagery and the Nature Conservancy Terrestrial Habitat Map. I also developed a generalized linear model to describe woodcock landscape selection during fall and spring migration using the Environmental Protection Agency Level III Ecoregions. I found woodcock in New York used a larger area during the breeding season than previous breeding season studies, and selected for open areas such as shrublands, grasslands, and wet meadows. There were notable differences between how male and female woodcock select for available resources. Male and female woodcock showed similar trends in selection of ecoregions during spring and fall migration. I recommend managers consider differences in male and female selection when developing habitat management plans for woodcock. I also recommend migration stopover location patterns to be

considered when developing these management plans, as stopover locations double as potential breeding locations for females in New York State.

Introduction

General Ecology

There are roughly one million species of flora and fauna threatened globally (Smith *et al.* 2023), making biodiversity conservation vital to preventing further species loss. Birds can serve as indicators of biodiversity loss (Rosenberg. 2019); however, since 1970, there has been an estimated net loss of 2.9 billion breeding birds, a reduction of 29% across biomes (Rosenberg 2019). Shorebirds specifically have been declining on a global scale (Watts *et al.* 2015). Population size estimates during fall migrations from 1980 to 2019 show nearly all (26 of 28) shorebird species are declining across North America (Smith *et al.* 2023). Over half of these species lost over 50% of their abundance during this period, with greatest declines in eastern North America (Smith *et al.* 2023).

The American woodcock (*Scolopax minor,* woodcock hereafter) is a migratory upland gamebird found across the Midwest and eastern United States and Canada. Though woodcock belong to the order *Charadriiformes,* shorebirds, they do not typically use the same habitats or landscapes as other closely related species. In fact, woodcock primarily use the upland portion of the landscape, whereas most other shorebirds use wet, lowland areas, and as their name implies, shorelands. Overall, these differences make woodcock an exception relative to others in their taxonomic family, as they cannot be managed the same as other shorebirds.

Habitat, landscape, and resource use

Woodcock use a variety of landscape and landcover characteristics over the duration of their annual cycle. Although their needs change between breeding and non-breeding season, research has shown ideal woodcock characteristics are young forests near open areas such as abandoned farmland, grasslands or pasture. They often use mixed (i.e. deciduous and coniferous trees) forests but are apparently unrestricted by specific vegetation type assemblages (McAuley *et al.* 2020). Woodcock appear to be more sensitive to forest structure than the species composition, with basal area, stem density, and tree height affecting habitat selection (Huinker 2020). Young and mid-aged forests (<30 years of age) interspersed with open areas are often used during the breeding season, where females place their nests and then raise their broods (Sepik and Derleth 1993). Males often select for wetland forest (mixed and deciduous) and upland deciduous forest (Slezak *et al.* 2023). Females generally require patches to be closer together than males (McAuley *et al.* 2020). Describing differences in male and female woodcock ecology is vital for managing habitats for breeding populations to ensure that the required resources are available for all woodcock on the landscape. Having an adequate amount of edge between forest and open areas is important to woodcock ecology. Woodcock typically nest and roost relatively close to forest edges, which are in greater abundance in patchy forests. While woodcock roost along edges, they also forage along them and into open areas with high soil moisture.

Woodcock forage almost exclusively in loam and sandy loam soil types (Rabe *et al.* 1983). These soil types, especially in proximity to water, retain moisture. This is critical for woodcock foraging as their primary diet is earthworms, which require adequate soil moisture. Landscapes that contain a mix of mesic forests, wetlands, and water bodies such as ponds, small lakes, and streams often have a positive association with woodcock presence for this reason (Klute *et al.* 2000).

Woodcock typically remain faithful to their nightly foraging sites for the duration of their time in either the breeding or wintering grounds, though fluctuations in earthworm densities can determine bird movements (Doherty *et al.* 2010). One study in the upper Midwest, USA showed most (91%) female woodcock movements were less than 400m, with 48% of movements less than 50m from roost sites in the fall (Doherty *et al.* 2010). Because woodcock do not stray far from their nightly foraging activity, ensuring the landscape has an adequate composition of landcovers is important. Elevation, landscape composition, and patch size may also influence woodcock habitat and landscape use (Hudgins *et al.* 1996, Klute *et al.* 2000). Elevation and slope could influence earthworm abundance, which has an effect on woodcock selection (Hudgins *et al.* 1996). While woodcock habitat characteristics have been defined in previous papers, not much is known about woodcock and patch sizes.

Order of Resource Selection

Microhabitat hierarchy was first recognized by Johnson (1980). The 4 orders of selection can be described as follows:

First order selection: Selection of species physical or geological range.

Second order selection: Selection of an individual or social group home range within a geographical range.

Third order selection: Selection of how habitat resources are used (i.e. which areas are used for breeding, which for foraging, etc…)

Fourth order selection: Selection pertaining to the areas distinguished by third order selection. For example, where nests are placed in breeding areas, or food available in foraging sites.

For this study, I focused primarily on second and third order selection. I described landscape characteristics within individual bird home ranges during the breeding season (third order). I described landscape use during spring and fall migrations (second order).

Migration Ecology

Migratory strategy refers to behaviors, such as pathway use, stopover site selection, and movement timing on an individual basis (Colwell 2010). Having greater migration strategy diversity in bird populations has been associated with slower population decline rates (Gilroy *et al.* 2016). In recent studies, during migrations, woodcock have not exhibited discrete migration strategies but instead strategies exist along gradients influenced by migration distance, duration, departure timing, and stopover behavior (Clements *et al.* 2024). In general, woodcock that migrated to and from more northern latitudes tended to cover greater distances during migration and took longer to do so (Clements *et al.* 2024). Because woodcock do not have a specifically defined strategy, it is important to look at how birds use the landscape on a bird-by-bird basis in a defined area, such as New York State (NYS).

New York State is geographically positioned in the Atlantic flyway, where landscapes and landcovers are used for breeding and migrating woodcock. Woodcock migrate from their breeding to nonbreeding areas from September to November, with most movement happening mid-October to mid-November (Myatt and Krementz 2007, Meunier *et al.* 2008).

Ecoregions are regions within the landscape which have similar patterns in resource quality, type, and quantity, ecosystems, and human effects on the landscape (Omernik 1995). Ecoregions can be defined by the managers in any area; however, the Environmental Protection Agency defines ecoregions for the United States to be used as a spatial framework for research, assessment, and monitoring of ecosystems in the country (Omernik and Griffith 2014). Using these regions are critical for creating structure management agencies across federal, state, and nongovernmental organizations (Omernik and Griffith 2014). These created ecoregions are consistent across the country, which allows for an easy comparison among large scale studies that use ecoregions as the spatial framework. Using ecoregions on this large scale is ideal for studies where an intricate level of detail is not needed, and all management practices can be considered at once. While research is starting to emerge on woodcock migration strategies (Clements *et al.* 2024, Fish 2021, Fish *et al.* 2024), little is known about how these birds might select landscapes at the ecoregion scale in North America. Studying migration at the ecoregion scale can give insight into how birds are using the landscape at a broad scale and indicate how birds are moving through the state.

Woodcock are itinerant breeders, which means, as a species, their temporal breeding and spring migration timing greatly overlap due to their ability to have 2 to 6 nest attempts in a year with a significant migratory movement among them (Slezak *et al.* 2024). This breeding style was recently described in Phainopepla (*Phainopepla nitens*), a songbird found in the southwestern United States (Baldassarre *et al.* 2019). Other bird species where indirect evidence shows an itinerant breeding style are common quail (*Coturnix coturnix*), yellow-billed cuckoo (*Coccyzus americanus*), orchard oriole (*Icterus spurius*), and water rail (*Rallus aquaticus*) (Slezak *et al.* 2024). Failed nest attempts are common in woodcock, and after these failed attempts a female woodcock is likely to move great distances (or continue migration) to attempt a second nest elsewhere in their range. This makes studying breeding season and migratory stopover locations vital in understanding woodcock ecology as a whole, since breeding and migration windows are not as distinct as they are in other species.

Populations and Management

Woodcock populations have had a 1.1% range-wide decline over the last 50 years (Seamans and Rau 2018). The U.S. Fish and Wildlife Service (FWS) manage woodcock populations in 2 management regions: central and eastern. These management regions were first suggested by Owen *et al.* (1977) and are the regions now being monitored through the American Woodcock Conservation Plan (Kelly *et al.* 2008). These regions were defined by band return data, which showed there is minimal overlap among birds from either region. This allows populations to be studied and managed separately (Seamans and Rau 2020). The eastern management region has had a 1.07% annual decline over the past 10 years (2012-2022), with a long-term decline of 0.84% annually from 1968 to 2022 (Seamans and Rau 2022). Wing collection studies indicate a decline in number of young birds/female adult, which suggests reduced productivity (Huinker 2020).

Woodcock have been studied on a statewide level in Maine (Sepik and Derleth 1993), Rhode Island (Masse *et al.* 2019, Slezak *et al.* 2023), and Pennsylvania (Miller and Jordan 2011), but there is less known about how woodcock use the landscape in New York. Annual surveys of spring singing grounds show Atlantic flyway woodcock, and New York specifically, have been declining around 2% annually since 1960, resulting in a cumulative loss of over 55% over the last 40 years (NYSDEC no date). Singing-ground surveys show a decreasing trend in New York from 1968 to 2023 (Seamans and Rau 2023, Figure 1). Because woodcock are slightly less sensitive to forest maturation than other species, such as the golden-winged warbler (*Vermivora chrysoptera*) (Bakermans *et al.* 2001), their decline indicates a bigger issue with their preferred early successional habitat. This led managers to list woodcock as one of the target species in the New York State Department of Environmental Conservation's (NYSDEC) Young Forest Initiative Strategic Plan (NYSDEC 2016).

The NYSDEC Young Forest Initiative Strategic Plan aims to understand the ecology of wildlife using early successional habitat. These habitats have become uncommon in the eastern United States, especially in the Northeast, due to forest maturation (DeGraff and Yamasaki 2003). Many early successional species are now extinct, extirpated, threatened, or species of management concern due to this loss (DeGraff and Yamasaki 2003). A subset of these species include the American woodcock, Eastern whip-poor-will (*Antrostomus vociferus*), Golden-winged warbler, New England cottontail (*Sylvilagus transitionalis*), and Snowshoe hare (*Lepus americanus*). Early successional habitat can be difficult to manage long-term, as this stage requires great and frequent levels of disturbance to maintain it (Huinker 2020). Fire, wind, Native American agriculture, flooding, and beavers have historically caused disturbances and this created a landscape where early successional land covers were common (DeGraff and Yamasaki 2003). These disturbances are no longer common because they can damage human infrastructure, impede development, and usually incur negative public perceptions of disturbance methods (Huinker 2020). Management is required to provide these habitats for disturbance dependent species (DeGraff and Yamasaki 2003).

The hunting season for woodcock in NYS aligns with the fall migration window (October to November). The Harvest Information Program (HIP) was created by the U.S. Fish and Wildlife Service in collaboration with state agencies to provide and annual estimate of hunter activity for all migratory gamebirds (Elden *et al.* 2002). The 2022-2023 HIP survey estimated 65,400 harvested woodcock in the Eastern management region, which was 12.1% less than previous years (Seamans and Rau 2023). Despite this, previous studies suggest this level of harvest does not negatively influence woodcock population growth rate (McAuley *et al.* 2005). Woodcock populations have been invariant to changes in hunting regulations, therefore management has instead focused on understanding and trying to improve habitat requirements.

Previous Techniques

Many previous woodcock movement studies relied on data from band recovery (Moore and Krementz 2017) and localized movements using short-range radio telemetry (Myatt and Krementz 2007). While still valuable, these approaches are not as conducive for a detailed look at habitat use, selection or movement ecology, on a bird-by-bird basis, especially for migration. This large gap in migratory data prompted the Association of Fish and Wildlife Agencies to identify migration ecology as one of the greatest research needs for the American woodcock (Case and Associates 2010). This, along with questions about how woodcock migration affects their population trends, led to the formation of the Eastern Woodcock Migration Research Cooperative (EWMRC).

The EWMRC was created in 2017 at the University of Maine. It is an international effort between the United States and Canada understand how migration influences woodcock population trends using global positioning system (GPS) and satellite technologies. This allows individual birds to be tracked from the start to finish of their migration pathways. Having access to migration pathways allows collaborators to answer questions about when and where woodcock are having the most trouble across their entire life cycle. This same technology and data can be used to understand woodcock stationary landscape use during the breeding season. By having access to individual woodcock movements, these data can be used to understand where woodcock are moving for the duration of the breeding window. Satellite transmitters require the bird to be captured only one time, without needing to be recaptured to collect the data. Satellite transmitters also allow researchers to monitor movements remotely, which reduces the risk of continual disturbance from tracking birds via radiotelemetry. These data can be used to explore questions about woodcock landscape use during the breeding and non-breeding seasons.

Statement of Objectives

The goal of this project is to describe American woodcock habitat use and selection in New York State to further the understanding of woodcock movement and resource selection. The primary objective is to describe breeding season habitat use and selection at the home range and core area scale and compare the differences in landcover selection between male and females. The second objective is to identify whether woodcock exhibit any selection at the Ecoregion level of stopover site location during migrations (fall and spring separately).

Research Questions

1. What landscape types and characteristics do American woodcock prefer and avoid in New York State during the breeding season?
2. What is the size of home ranges and core use areas for American woodcock during the breeding season in NYS?
3. Does resource selection differ between males and females?

4. How do landscape characteristics and composition within home range and core areas differ between males and females?
5. Do woodcock show selection or avoidance for ecoregions during their migratory stopovers?

Hypotheses

1. American woodcock are going to select for habitat in close proximity to wetlands.
2. American woodcock are going to select for open areas (grassland, shrubland, etc.).
3. Resource selection will be the same between male and female birds.
4. Female home range sizes will be larger than males.
5. Male home range characteristics will be more diverse than females.
6. American woodcock will be more selective of landscape use during breeding season compared to migration.

Study Area

The area used for this study was New York State, USA including a 50 km buffer around the perimeter (Figure 2). This buffer added locations from Pennsylvania, USA, Connecticut, USA, and New Jersey, USA into analysis. The total area included in this study was 14,131,331 ha. Woodcock locations recorded from 2019 to 2023 were included in this study. These locations spanned the fall (September – November), spring (March – May), and summer seasons (June – August). No winter locations were included as woodcock do not spend the winter season in NYS. Other dominant wildlife species across NYS include white-tailed deer (*Odocoileus virginianus*), gray squirrels (*Sciurus carolinensis*), red fox (*Vulpes vulpes*), Eastern cottontail (*Sylvilagus floridanus*), striped skunks (*Mephitis mephitis*), raccoon (*Procyon lotor*), eastern chipmunks (*Tamias striatus*), bald eagles (*Haliaeetus leucocephalus*), red-tailed hawk (*Buteo jamaicensis*), wild turkey (*Meleagris gallopavo*), and beaver (*Castor canadensis*).

Due to its position near the Great Lakes, NYS experiences variety in climate and weather patterns. In general, NYS is a mid-latitude, humid, continental climate with warm summers and cold, snowy winters (Commission for Environmental Cooperation 2011). Severity of precipitation is influenced by the proximity of a given area to the Great Lakes, with more severe snow and rain happening closer to the lakes. Dominant tree species across most of the state are sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*), red oak (*Quercus rubra*), white oak (*Quercus alba*), and eastern white pine (*Pinus strobus*). New York State exhibits a range of different topographies and elevations. The range of elevation in the state is from sea level (e.g. coastal Long Island) to 5,343 ft (e.g. Adirondack Park) (U.S. Geological Survey no date). The topography includes two mountain ranges (Adirondack Park and Catskills Mountains), valleys, hills, and areas of level terrain.

Much of the state has been converted to croplands, with corn, soybeans, and wheat being the most farmed vegetable (U.S. Department of Agriculture no date). Large pastures are also used for dairy farming (U.S. Department of Agriculture no date). Other agricultural land use includes vegetable crops, orchards (especially apple), and vineyards. As of 2023, there are 6.5 million acres of land being used for farm operations in NYS (U.S Department of Agriculture 2023). NYS is around 35 million acres in size, therefore farm operations make up roughly 18.6% of the state. Much of the state has been developed into major cities, such as New York City, Albany, and Buffalo. Smaller human developments are ubiquitous across the state.

Methods

Field Capture – New York State

Field capture in NYS was accomplished by a team of volunteers, biologists, scientists and students from NYSDEC, US Forest Service, State University of New York-Brockport and Braddock Bay Bird Observatory. Beginning at sunset, we listened for male woodcock to pinpoint potential searching locations. When a bird was visually or audibly confirmed at a location, a plan was developed to attempt capture. To assist with visual confirmation, we used forward looking infrared (FLIR) thermal imaging scopes (Teledyne FLIR) which detect heat signatures. If we detected a bird, we approached carefully with a hand net and spotlight. Upon spotting the bird visually, one individual strobed the spotlight to disorient the bird while a second individual attempted to catch the birds in a hand net. When FLIR units were unavailable or unsuccessful, we used alternative methods such as spotlights to detect woodcock eyeshine and mist nets with an audio lure. In 2022, we captured 10 birds using the FLIR/hand net method. In 2023, we used the mist net method to capture 6 birds, and the FLIR/hand net method for the other 4 birds.

For each bird captured, biologists determined the bird's sex using bill length, weight, the shape and size of the first 3 primary feathers, and length of the wing chord (Martin 1964). Each bird was assigned an age (second year or after second year) based primarily on the color of the inner 4 secondary feathers, with other noticeable molt considered (Martin 1964). We then banded each bird with a U.S. Geological Survey aluminum bird band (size 3). For each bird, we recorded the following information: the NYSDEC region of capture, date, time, capture method, GPS coordinates, GPS tag ID (if applicable), bander initials, band number, sex, age, weight (g), bill length (mm), tarsus length (mm), wing chord (mm), and any additional comments about the bird's condition and release. Birds received a GPS transmitter if their weight was sufficient as the transmitter weight (5-6g) could not exceed 3% of a bird's total body weight.

Transmitter deployment and duty cycles

In April and May 2022, 10 Lotek PinPoint ARGOS 120 GPS transmitters (model 120; Lotek Wireless INC., Newmarket, Ontario, CA) were deployed all on female woodcock. The transmitters were distributed among NYSDEC Regions 4 (*n*=2), 6 (*n*=4), 7 (*n*=1), and 8 (*n*=4; Figure 3). We waited to deploy transmitters until after April 19th because this is when I believed most migration had ended (E. Blomberg, personal communication). The first transmitter was deployed on April 20, 2022 and the final on May 11, 2022.

In 2023, 10 additional Lotek 120 transmitters were deployed on male (*n*=5) and female (*n*=5) woodcock. The transmitters were distributed among NYSDEC

Regions 4 (*n*=2), 6 (*n*=3), 7 (*n*=1), and 8 (*n*=4; Figure 4). The first transmitter was deployed on April 20, 2023 and the final on June 6, 2023. Most transmitters for each year were deployed on woodcock found in wildlife management areas (WMAs) or multiple use areas (MUAs).

All transmitters were programmed using the Lotek PinPoint Host application (Lotek Wireless INC., Newmarket, Ontario, CA) and charged prior to deployment. The programmed schedule for the transmitter to take locations is called the duty cycle.

In 2022, I programmed the duty cycle to take one location every 2 days and 3 hours starting April 30, 2022 until October 31, 2022. Starting November 11, 2022 to April 23, 2023, I programmed the duty cycle to take a location every 9 days and 6 hours. There was a 10 day gap in the duty cycle due to a programmer error. Finally, starting April 23, 2023, I scheduled the transmitters to return one location every 2 days and 3 hours and this cycle lasted until the transmitter battery died. Adding 3 or 6 hours to any given interval ensures day and night locations would be recorded over the history of each transmitter.

In 2023, I programmed the transmitters with a different duty cycle, dubbed the "Lazarus" schedule (L. Berigan, personal communication). This duty cycle was developed with the intention to record locations in a bird's breeding and non-breeding areas. The Lazarus schedule had the transmitters take locations every 1 day and 12 hours from April 2023 to July 2023. The transmitter then went dormant to conserve battery for the duration of migratory movements from the breeding to wintering grounds. In February 2024, the transmitters activated for 3 days, taking 1 location/day in the wintering grounds. The transmitter then again went dormant and was programmed to reactivate in April 2024 to transmit a location every day until the battery died.

In addition to the transmitters deployed in NYS, additional data was provided by the Eastern Woodcock Migration Research Collective (EWMRC). From Fall 2017 to Spring 2023, the EWMRC deployed 596 GPS transmitters on woodcock captured in 15 states and 3 Canadian provinces. These transmitters provided data on 517 migration attempts and 405 full migratory paths and from this I created a subset of data for birds that used locations within a 50km buffer around New York State within the breeding season time range. This added an additional 25 birds to analyses (n = 9 females, n = 16 males) in addition to the 20 transmitters deployed during the 2022 and 2023 field seasons. As a result, I used 44 individual woodcock for home range analyses and 198 in migration analyses. Although transmitters collected data at different time intervals in my study, I was able to use all the locations that met my criteria to estimate home range and core area use and for all subsequent analyses.

All location data was uploaded via ARGOS satellites to the Movebank animal movement database (Kays 2022, Wikelsi 2023). This information is updated regularly to ensure the most up-to-date dataset for analyses. Movebank data can be important directly into program R using the move package (Kranstauber *et al.* 2022).

Home Ranges – Breeding Season

I estimated the size of home ranges for males and females separately during the breeding season. I defined the breeding season as May 15 to October 15 based on previous woodcock studies (Fish *et al.* 2021). This time period inherently includes all phases of the breeding season, from nesting through post fledging. I calculated home ranges for all birds which had >5 locations and those locations had to span at least 21 days. After applying these criteria, I used 44 birds in analyses (n=24 females, n=20 males).

To create home ranges, I performed a kernel density analysis for each individual using Program R version 4.2.3 (R Core Team 2021). I accomplished this by using the adehabitatHR (Calenge 2006) and amt (Siger *et al,* 2019) packages. While many previous home range studies use the 95% contour home range (Masse *et al.* 2014, Slezak *et al.* 2023), I used the 80% home range contour for this analysis because some birds in my study had one or 2 foray locations which positively biased the overall size of their home ranges. I believe these 80% home ranges were more reflective of the resources and landscapes birds likely used. I also calculated and estimated core home ranges using the 50% kernel density (Masse *et al.* 2014). I ran descriptive statistics on the home ranges of males and females separately to evaluate potential differences.

I used the distance matrix tool in QGIS version 3.26.3 Buenos Aires (QGIS Association 2023) to calculate the distance between each individual bird's locations at the home range and core area scale. I did this to describe how clumped locations are on the landscape, giving an indication of how birds are using their home ranges and core use areas. I calculated summary statistics (mean, median, standard deviation, maximum, and minimum) on each data set. I used these to compare the differences in location grouping between males and females at each use scale.

I used the landscapemetrics package (Hasselbarth *et al.* 2019) to describe the various landscape traits that I predicted might be relevant to woodcock within their home ranges. I calculated metrics used to describe landscape diversity, aggregation, complexity, and overall edge (Ene and McGarigal 2023, Fowler *et al*. 2023). These metrics included Shannon's diversity index, Simpson's diversity index, patch richness, patch richness density, patch density, mutual information, number of patches, total edge, edge density, and landscape percentage (Table 2). Using the same package, I calculated the landscape composition for each home range. I summarized this for the home range and core area estimates. I calculated these data for each individual home range averaged them for males and females. I then found the percentage of each landcover type and averaged them across all male and female home ranges. I then ran a Mann-Whitney U test on all landscape metrics in R. I used a Mann-Whitney U because these data did not fit the assumptions for a parametric t-test.

I used the United States Protected Areas Database (USPAD) developed by the United States Geological Survey as a reference for public and/or actively managed land where birds home ranges were found (New York, Connecticut, Pennsylvania, and Rhode Island). I confirmed the accuracy of the USPAD information by cross checking with available NYSDEC land data layers. I did this by overlaying the

USPAD layer over the NYSDEC land data layer and calculating the overlap percentage. I calculated the percentage of public land within each bird home range and averaged the percentages across all males and females. I ran a Mann-Whitney U in R on the percentages to test for differences between males and females.

Resource Selection – Breeding Season

I modified the Terrestrial Habitat Landcover Map (THLM) created by the Nature Conservancy (Anderson *et al.* 2013) as the base landcover variable for all models. The THLM has a 30x30 m raster pixel size and, before modification, I found many locations of woodcock were not accurately described. Therefore, I modified it by creating a new landcover vector classification layer using ArcMap version 10.2 (ESRI 2011, ArcGIS Desktop version 10.2), whereby I interpreted all terrestrial landcovers with satellite imagery then digitized them. For all non-terrestrial landcovers, I accepted the wetland classifications and geographic extent of the National Wetlands Inventory data (U.S. Fish and Wildlife Service 2023). I did this within each individual's home ranges. My modified landcover map contained the following 10 landcover classifications: mature wet forest, deciduous upland forest, mixed upland forest, upland conifer forest, wet meadow/shrub marsh, emergent marsh, open water, open space, agriculture, and developed land, and these can be easily related back to the THLM (Table 1). Open space and water were each broad categories. Open space included pasture, grasslands, low shrublands, and other open grassy areas on aerial imagery. Water included open water (ponds, lakes, etc…) and riparian zones.

Within ArcMap, I plotted 5,000 random locations for each individual home range (females = 120,000 random, males = 100,000 random). I then extracted the landcover type that each woodcock and random location was located on using the spatial join tool in ArcMap, then extracted distance to nearest road, wetland, general edge, forest edge, and estimated elevation at each location. For distance calculations, I removed any locations that were closer to the home range edge than the calculated feature. This was to ensure the correct distanced were being used, as ArcMap could not distinguish between home range edge and an ecological edge. I calculated the elevation at each location by using the elevatr package in R (Hollister 2023). This package uses the latitude/longitude data to identify elevation through the United States Geological Survey Point Query Service. I performed these analyses for males and females separately.

I built a mixed effect generalized linear model in R to model the relationship among used bird locations and available landscape covariates. I designated used bird locations and available locations as the independent variable and the landcover type, distance to resources, and elevation as the dependent variables. This model ran as a logit function, meaning the independent variable was denoted by ones and zeros. Ones denoted a used bird location, whereas zeros denoted a random available location on the landscape. The random effect in these models was bird ID. Prior to running any models, I scaled the distance calculations and elevation to standardize them around zero. I then ran a correlation matrix and removed any variables which had a correlation >0.7. I did this to remove autocorrelation among variables from the models. The variables included in the full model were landcover type, scaled distance to any edge, scaled distance to forest edge, scaled distance to wetland edge, scaled distance to road, and scaled elevation. I used the adehabitatHS (Calenge and Basille 2023), arm (Gelman and Su 2022), and lme4 (Bates *et al.* 2015) packaged to create the models. I examined 4 competing models (Table 3) for females and 3 competing models for males (Table 4). I used Akaike's Information Criterion (AIC_c) model selection to determine the best fit model for males and females. I considered the model with the least AIC_c as the best approximating model. I assessed model fit by examining the marginal (variance explained by fixed effects) and conditional R^2 (variance explained by the fixed and random effects; Nakagawa and Schielzeth 2012).

Migration Ecoregion Selection

I defined migration as October 15 to May 15 of any given year. I selected migration locations that fell in this time range within the 50km buffer around NYS. The number of locations/bird ID and the time between locations were not necessary for migration analysis, therefore each bird needed 1 or more location within the NYS buffer to be included. I separated the locations by sex and migration season; fall migration males (n=273), fall migration females (n=193), spring migration male (n=461), and spring migration females (n=601).

To examine landscape use during migration, I plotted birds within the Environmental Protection Agency ecoregions. I used ecoregion level III which in NYS and the surrounding area includes: Algonquin/Southern Laurentians (ASL), Atlantic Coastal Pine Barrens (ACPB), Eastern Great Lakes Lowlands (EGLL), Erie

Drift Plain (EDP), Lake Erie Lowland (LEL), North Central Appalachians (NCA), Northeastern Coastal Zone (NECZ), Northern Allegheny Plateau (NAP), Northern Appalachian and Atlantic Maritime Highlands (NAAMH), Northern Piedmont (NP), Ridge and Valley (RV), and Water.

I plotted random locations across the state at a 50 to 1 ratio using the total number of bird locations (n=1,528). I plotted 76,400 random locations. I then removed any locations that were located in the ASL, LEL, or water ecoregions, as no birds used these ecoregion types. Additionally, I removed random locations in the EDP ecoregion for the female fall migration analysis and male migration analyses because no birds used this ecoregion type. I removed NCA from male migration analyses for the same reason.

I ran a generalized linear model using the lme4 and arm packages in R to model bird stopover locations relative to available ecoregions within the state. I designated bird stopover locations and random available locations as the independent variable and the ecoregions as the dependent variable. This model ran as a logit function, meaning the independent variable was denoted by ones and zeros. Ones denoted a used bird location, whereas zeros denoted a random available location on the landscape. I then analyzed a correlation matrix and removed any variables with a correlation >0.7. I did this to remove autocorrelation among variables from the models. I ran each model twice; once including NYS tagged birds and once excluding NYS tagged birds. I did this to test for bias in the sample due to birds captured in the study area. I created 4 selection models based on sex and migration season.

I conducted a final analysis on fall migration to evaluate selection relative to NYSDEC flush rate data. Flush rate data comes from hunter surveys, where the number of woodcock flushed per hour is recorded (NYSDEC 2021). I combined male and female locations located within NYS borders, excluding locations in the buffer zone. I had a total of 210 locations for this analysis. I created random points at a 50:1 ratio, therefore 10,500 random points were created. I removed any random locations that fell within the Erie Drift Plain, Water, and Lake Erie Lowland ecoregions as no bird locations were found in these categories. I ran a generalized linear model on these locations using the same method as all other migration analyses.

Results

Home Range

I calculated the home ranges for 24 female and 20 male woodcock. For females home ranges averaged 297.6 ha (105.2 ha SE) and ranged from 2,241.4 ha to 1.5 ha. For males, home ranges averaged 541.7 ha (144.1 ha SE) and ranged from 2,232.7 ha to 6.4 ha. The mean number of locations/female was 36 and the mean distance among locations/individual was 554 m. The mean number of locations/male was 19 and the mean distance among locations/individual was 911 m.

Mixed upland forest was the most common available landcover type, on average, in male and female home ranges, whereas conifer forest was the least common (Table 5). On average, female home ranges contained twice as much public lands compared to males (Table 5), however this was not statistically different ($P > 0.05$). Only 2 of the 11 tested landscape metrics were statistically significant: number of patches and total edge ($P < 0.05$, Table 6). Patch richness density was just above the statistical cutoff for significance of $P = 0.05$ ($P = 0.062$). All other landscape metrics showed no statistical significance, with edge density, Shannon's evenness index, and Simpson's diversity index being the least significant (Table 6). On average, the number of patches and total edge was over 2x greater for the males than the females (Table 5).

Core Use Range

Female woodcock core use area averaged 1,12.2 ha (38.2 ha SE) whereas male core use area averaged 225.5 ha (63.6 ha SE). The largest female core range was 761.4 ha and the smallest 0.6 ha. The largest male core range was 1,033.2 ha and the smallest 2.4 ha. The mean number of locations/female was 31 and the mean distance among locations/individual was 279 m. The mean number of locations/male was 17 and the mean distance among locations/individual was 702 m.

Mixed upland forest was the most common available landcover type, one average, in male and female home ranges (Table 5). For females, emergent marsh was the least common whereas for males conifer forest was the least common (Table 5). On average, female home ranges contained twice as much public lands compared to males (Table 5), however this was not statistically significant ($P > 0.05$). None of these landscape metrics were statistically significant at the core home range (Table 7). Patch richness density, number of patches, and total edge were just above the cutoff for statistical significance at $P = 0.05$.

Resource Selection – Breeding Season

Females and males each used wet meadow/shrub marsh and open areas (shrublands/grasslands, fields, etc.) in a greater proportion than what was available on the landscape within the home range (i.e., selected for). Females and males each used upland conifer forest, developed land, and agriculture less than what was available on the landscape (i.e., selected against). Females and males used water in proportion to what was available. Females and males tended to use locations further from wetland edges, but nearer to roads and forest edges. Elevations had no effect on male or female locations (Figure 4).

Differences in landscape use between males and females existed in mature wet forest, mixed upland forest, and deciduous upland forest, where males used a great proportion of mature wet forest and deciduous upland forest, while females used these landcover types in proportion to what was available to them on the landscape with slight inclination towards avoidance. Females used mixed upland forest less than what was available on the landscape, and males used this landcover type in proportion to what was available on the landscape with a trend towards mixed upland forest (Figure 4).

Fall Migration

I analyzed 466 total locations collected during fall migration. I included 193 female locations (average 5/bird) and 273 male locations (average 8/bird). Females used the Northeast Coastal Zone in greater proportion to what was available on the landscape. Females used the North Central Appalachians, North Appalachian and Atlantic Maritime Highlands, Eastern Great Lakes Lowlands, and Atlantic Coastal

Pine Barrens less than what was available on the landscape. Females used Ridge and Valley, Northern Piedmont, and Northern Allegheny Plateau in proportion to what was available on the landscape (Figure 5). Males used all ecoregions less than what was available on the landscape (Figure 6). NYS tagged birds did not influence the selection results.

The fall migration analysis with the sexes combined showed no positive selection for any available ecoregions (Figure 13). Woodcock showed negative selection for North Appalachian and Atlantic Maritime Highlands, Great Lakes Lowlands, and Atlantic Coastal Pine Barrens. Woodcock selected Ridge and Valley, Northern Piedmont, Northern Allegheny Plateau, Northeast Coastal Zone, and North Central Appalachians in proportion to what was available in the landscape.

Spring Migration

I analyzed 1,062 total locations collected during spring migration. I included 601 female locations (average 8/bird) and 461 male locations (average 8/bird). Females used Ridge and Valley, Northeast Coastal Zone, Eastern Great Lakes Lowlands, and Erie Drift Plain at a greater proportion to what was available on the landscape. Females used North Central Appalachian and Atlantic Coastal Pine Barrens less than what was available on the landscape. Females used Northern Piedmont, Northern Allegheny Plateau, and North Appalachian and Atlantic Maritime Highlands in proportion to what was available on the landscape (Figure 5). Males used Ridge and Valley, Northeast Coastal Zone, and North Central Appalachian in greater proportion to what was available on the landscape. Males used Atlantic

Coastal Pine Barrens less than what was available on the landscape. Males used Northern Piedmont, Northern Allegheny Plateau, North Appalachian and Atlantic Maritime Highlands, Lake Erie Lowlands, and Erie Drift Plain in proportion to what was available on the landscape (Figure 6). NYS tagged birds did not influence the selection results.

Discussion

My examination of woodcock resource selection found differences between how male and female woodcock use the landscape within their home ranges. I found evidence against my hypothesis that birds selected locations in closer proximity to water. Males and females had a slight preference for locations further from wetland edges. I found support for my hypothesis that woodcock, regardless of sex, will select for open areas. Although I hypothesized resource selection would not differ between male and female birds, I found slight differences in how birds of either sex used the landscape. My examination of woodcock ecoregion selection during migration found that woodcock select for different parts of the state during spring and fall migration. I found evidence against my hypothesis that female home range sizes will be larger than male home ranges. Woodcock showed greater selection for certain ecoregions during spring migration, whereas they show greater selection against ecoregions during fall migration. I met my objectives to describe woodcock landscape selection during breeding season and migration and compared differences in use based on bird sex.

Male woodcock in New York State had larger home ranges than females, which differs from previous woodcock studies where female home ranges are larger (Allen *et al.* 2020, Horton and Causey 1979, Slezak *et al.* 2023). There has been previous reporting of males having a larger home range than females. Sepik and Derleth (1993) found females had an average home range of 42 ha and males an average of 74 ha. This study collected data from June to October 1982-1984. In general, woodcock home ranges are larger in New York than in other states, such as a recent publication from Rhode Island (Slezak *et al.* 2023). My study included a longer time period than the Slezak study (May 15 to October 15 compared to May 15 to September 1), which could include a larger number of woodcock movements. The Slezak *et al.* study used radiotelemetry data to create home ranges, whereas my study use satellite transmitters with varying duty cycles. This could create variation in where the birds are when locations are taken. All of the locations in the Slezak study were found within wildlife management areas, whereas my locations were found across the state on public and private land. The method of calculating kernel density and home range estimates in R was the same for both studies, however the Slezak study used the 95% contour whereas I used the 80% contour. The average home range size in Rhode Island males was 35.0 (+/- 10.7) ha and the average home range for Rhode Island females was 78.7 (+/- 46.4) ha. These home ranges are smaller than the NYS bird core use. Larger home ranges in NYS could indicate woodcock require a larger area to access all their needed resources. Males requiring a larger home range could indicate they need more space to find a mate during the breeding season because overall densities of females might be less in New York compared to Rhode Island. This could also indicate they need a larger area to have an adequate mosaic for their needs.

Other factors that could influence home range size and selection in NYS compared to other states is the amount of agriculture and animal farming. Approximately 18.6% of the land in NYS is used for crops and animal farming, whereas in Rhode Island only 9% of the land is used for these purposes (U.S. Department of Agriculture 2023). In Maine, only 5% of the state is used for agricultural purposes (U.S. Department of Agriculture 2023). NYS having such a large proportion of agriculture, which woodcock avoided, could cause these larger home ranges. Agricultural fields interspersed could cause fragmentation of the forests and open areas that woodcock do use, and a larger area may be needed to avoid the agricultural landcover type.

Though home range and core use sizes differed, the general landcover selection aligned with previous studies (Masse *et al.* 2014, Slezak *et al.* 2023). Woodcock of either sex selected for open areas and wet meadow/shrub marsh. These landcover types are similar in their vegetation structures which align with how woodcock are known to use the landscape for roosting and foraging. Woodcock of either sex selected against active agricultural fields, human development, open water, and upland conifer forest, therefore areas with a great amount of these landcover types should be avoided when managing for woodcock. There were slight differences in how males and females use the landscape. Males selected for deciduous upland forest and mature wet forest, where females did not. Females selected for emergent marsh, where males did not. Females may use the emergent marsh for foraging rather than mature wet forest; each of which have the required moist soils. Variations in flooding could influence woodcock on a bird-by-bird basis, depending on the hydraulic cycle of the specific wetland they are near. The average emergent marsh area/home range was small for all females, only 58% of the birds in this study had emergent marsh in their home range.

Male and female woodcock selected for areas closer to forest edges and roads. Being close to forest edges aligns with known woodcock ecology, as they are considered an edge species. Selecting locations closer to roads is less frequently reported. Although artificial, roadways can create open areas and fragment habitat, which are each known to increase woodcock abundance (Masse *et al.* 2019). Because all roadways, regardless of size, were considered for this analysis, further research is needed into how roadways play into woodcock ecology. The woodcock in this study, regardless of sex, selected for further distances from wetland edges. All wetland types were considered for this analysis; therefore, I did not consider seasonal flooding. Further research is needed to determine whether woodcock prefer any specific wetland types. Woodcock having no preferences in either direction for elevation lines up with previous woodcock studies (Slezak *et al.* 2023), though woodcock abundance increasing at higher elevations was reported in Rhode Island (Masse *et al.* 2014).

Females had shorter distances among used locations than males, which is expected during the breeding season. I calculated distances among used locations to describe the bird location patterns on the landscape. Shorter movement distances make sense for females that are nesting or rearing a brood. Variation in transmitter duty cycles could have had a slight influence over location clustering, however I did not expect this to make a large difference.

Because New York State does not have a statewide landcover map at the same spatial resolution as other states and provinces do, such as Rhode Island and Nova Scotia (Masse *et al.* 2014, Gutowsky *et al.* 2020), I created a new layer by digitizing aerial imagery to modify the original Terrestrial Habitat Landcover layer. I digitized 10 landcover layers to capture woodcock third order selection. The layer I created was more accurate than the original raster data, as it better portrayed edges on the landscape. The layer I created also considers smaller patches within the landscape than the original habitat map. Having a patchy, or mosaic, landscape is also important to woodcock ecology. My layer was created based on aerial imagery, and woodcock could have perceived the landscape differently. I believe my approach more accurately represents how woodcock used landcovers and landcover edges. One important aspect of woodcock ecology I did not consider was forest stand age. Woodcock require early successional (e.g. young) forest, which was difficult to distinguish using aerial imagery due to the resolution and ephemeral nature of young forests. New York State did not have an accurate stand age layer for the entire study site; therefore, I was not able to use this in my analysis. Woodcock selected for wet meadow/shrub marsh, which I believe to be the closest landcover type to early successional forest.

There were not many differences between male and female home ranges described by the calculated landscape metrics. At the 80% kernel density home range, there was a significant difference in the number of patches and total edge between males and females. On average, males had a larger number of edges and patches within their home range landscape than females. While woodcock are an edge species, males require a larger number of patches than females during breeding. Males may move around more often than females, as females will be spending more time attending a nest. Males will also mate with multiple females, therefore will require a larger area to attract females. All other landscape metrics were not significantly different between males and females. There was no statistical difference between males and females at their core use range. I expected there to be no difference between males and females, though finding a difference in patch number and edge makes sense ecologically. When considering woodcock habitat, it is important to think about the diversity, aggregation, complexity, and ratio of area versus edge. Because the differences in these metrics between males and females are so minimal, these data can be used as a reference point for management (Table 6, Table 7).

There are differences in the ecozones used during fall and spring migration for males and females. In the fall and spring, females selected for NECZ and against NCA and ACPB. In the fall, only one ecoregion was selected for, and the rest were either selected against or birds showed no selection for. In the spring, females showed positive or no selection for most available ecoregions. Males showed a similar pattern in their selection. In the spring, males selected against all ecoregions where bird locations were recorded. In the spring, all ecoregions excluding ACPB were either selected for or showed no selection. Similar patterns of birds showing more favorable selection in the spring could indicate birds are more likely to use New York as a stopover location in the spring than in the fall. I looked at migration on a very broad scale, therefore any differences in landscape that could influence selection would be difficult to detect at this level. Snowfall, ground freezing, frost, and other weather factors could play an effect on how birds select stopover locations during migration. Woodcock were described as itinerant breeders (Slezak *et al.* 2024). New York lands in a unique spot in their migratory pathway, where birds are likely to stop for a breeding attempt while others continue their migration. Female woodcock migrating through New York may be more selective in the spring, as their stopover locations could also be potential breeding home ranges.

Combined woodcock fall migration selection had some similarities yet some differences with NYSDEC flush rate survey data (Figure 13, Figure 14). The Great Lakes Plain, Oswego Lowlands, and East Ontario Plain management unit aggregates are found within the Great Lakes Lowlands ecoregion. Woodcock showed selection against these ecoregions, and NYSDEC flush survey data showed these aggregates had a less frequent flush rate than others (NYSDEC 2022). By contrast, the North Appalachian Hills, Central Appalachian Plateau, East Appalachian Plateau, and Oneida Lake Plains management unit aggregates overlap with the North Appalachian Plateau ecoregions. Woodcock were neutral towards the NAP ecoregion, however the flush rate surveys showed frequent rates in these aggregates. Many of the woodcock in my study used ecoregions associated with NYS Long Island but there was insufficient data from NY DEC to estimate a flush rate in this region. I failed to find strong evidence that fall-migrating woodcock selected for ecoregions that aligned with where NYDEC found the greatest woodcock flush rates.

Future Research

Future research is needed to refine understanding on how woodcock use the landscape in New York during the breeding season. Examining habitat variables on a smaller spatial scale could be used to determine which resources are most important to woodcock during migration. Previous EWMRC studies looked into woodcock migration strategies and found differences based on starting latitude (Clements *et al.* 2024). Comparing migration strategies to landscape use could be used as a new perspective on woodcock migration. Further analysis into migration considering the itinerant breeding style could influence management decisions for the breeding season.

Future research is also needed to look at soil type and composition in comparison to soil types in New York State. Due to the cyclic nature of wetlands, more research is needed into how different wetland types influence woodcock selection. Woodcock locations were taken at different times during the day, therefore comparing diurnal to nocturnal locations to these models could add a layer of understanding to woodcock use. My resource selection analyses could be used to initiate a spatially explicit map detailing woodcock selection likelihood across New York State.

Management Implications

Differences in male and female use should be considered when creating woodcock management plans, especially in relation to breeding season. To create new and improve current woodcock habitat, management should target areas with the key factors already available. Woodcock target areas should have the appropriate forest type (deciduous upland and mature wet forests rather than upland conifer forest) with an adequate amount of edge and open areas. A minimum of 25 to 91 patches should be on the ideal woodcock landscape, with 6,500 m to 33,000 m of edge available. The amount of edge will vary based on the number of patches. For female woodcock, migration landscape use can be an indicator for breeding habitat quality. Creating suitable stopover habitat is important so females can begin nesting earlier if habitat requirements are met, and so birds that continue to migrate have enough resources to successfully make it to the end of their migration pathways. New York State managers should consider managing a larger area when targeting woodcock in their management plans. My findings emphasize the importance of private landowner management because the majority of woodcock home ranges were found on private land. Including private landowners in statewide management plans for woodcock will increase the abundance of required resources for woodcock.

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Tables

Table 1. The landcover types used to evaluate American woodcock resource use during the breeding season in New York State from 2018-2023. Each landcover was digitized in ArcGIS and was based on a source layer (i.e. Source) from the Nature Conservancy Terrestrial Habitat Map (Andersen et al. 2013) and National Wetland Inventory map (U.S. Fish and Wildlife Service 2013).

Landcover Type	Source
Agriculture	Photo interpretation and NTHM*
Deciduous upland forest	Photo interpretation and NTHM*
Developed	Photo interpretation and NTHM*
Emergent marsh	National Wetland Inventory (palustrine emergent type)
Mature wet forest	National Wetland Inventory (palustrine forested type)
Mixed upland forest	Photo interpretation and NTHM*
Open land	Photo interpretation and NTHM*
Upland conifer forest	Photo interpretation and NTHM*
Water	National Wetland Inventory (open water and riverine type)
Wet meadow/Shrub marsh	National Wetland Inventory (palustrine scrub-shrub type)

*Northeastern Terrestrial Habitat Map

Table 2. A description of landscape metrics calculated for the home range and core area scales for male and female woodcock in New York State during the breeding season (May 15 – October 15).

Metric	Landscape Characteristic	Level	Units
Shannon's diversity index	Diversity	Landscape	Information
Simpson's diversity index	Diversity	Landscape	none
Patch richness	Diversity	Class	none
Patch richness density	Diversity	Class	*n*/100 ha
Patch density	Aggregation	Class	*n*/100 ha
Shannon's entropy	Complexity	Class	none
Mutual information	Complexity	Class	none
Number of patches	Aggregation	Landscape	none
Total edge	Area and edge	Landscape	m
Edge density	Area and edge	Landscape	m/ha
Shannon's evenness index	Diversity	Landscape	none

Table 3. Top 3 models comparing the change in Akaike's Information Criterion (Δ AIC), marginal R^2, and conditional R^2 for satellite global positioning system (GPS) tracked female woodcock in New York State, USA during the breeding season (May 15 – October 15; *n* = 24). Factors included landcover type, elevation, and distances (dist.) to several features.

Model	AIC_c	Δ AIC_c	Marginal R^2	Conditional R^2
Landcover + Dist. to forest edge + Dist. to any edge + Dist. to road + Dist. to wetland + Elevation	6,989.9	0	0.089	0.677
Landcover + Dist. to forest Edge + Dist. to any edge + Dist. to road + Dist. to wetland	6,988.2	1.7	0.089	0.675
Landcover + Dist. to forest edge + Dist. to road + Dist. to wetland	6,986.5	1.7	0.089	0.675

Table 4. Top 2 models comparing the change in Akaike's Information Criterion (Δ AIC), marginal R^2, and conditional R^2 for satellite global positioning system (GPS) tracked male woodcock in New York State, USA during the breeding season (May 15 – October 15; *n* = 20). Factors included landcover type, elevation, and distances (dist.) to several features.

Model	AIC_c	ΔAIC_c	Marginal R^2	Conditional R^2
Landcover + Dist. to forest edge + Dist. to any edge + Dist. to road + Dist. to wetland + Elevation	3,307.7	0.0	0.177	0.45
Landcover + Dist. to forest edge + Dist. to road + Dist. to wetland + Elevation	3,306.9	0.8	0.176	0.45

Table 5. Average landcover and ownership type percentage, and landscape metrics for male (n = 20) and female (n = 24) home ranges and core use levels during the breeding season (May 15 – October 15) in New York State. Landcover types were modified from The Nature Conservancy Terrestrial Habitat Map. Ownership type was determined from the Protected Areas Database (U.S. Geological Survey no date). Bold indicates a statistical difference between male and female.

	Female		Male	
	Home Range	Core Area	Home Range	Core Area
Landcover				
Agriculture	16.1	17.9	17.5	15.2
Developed	8.3	7.5	8.7	7.0
Deciduous upland forest	17.9	9.7	16.1	10.6
Emergent marsh	2.4	2.5	1.6	2.7
Mixed upland forest	22.3	33.0	18.8	32.2
Mature wet forest	10.4	10.3	9.4	11.0
Open land	14.3	6.6	15.8	8.7
Upland conifer forest	1.4	2.9	3.4	1.9
Water	2.8	4.3	3.0	3.6
Wet meadow/Shrub marsh	4.1	5.2	5.7	7.2
Ownership type				
Public (%)	28.0	31.4	15.1	15.7
Private (%)	72.0	68.6	84.9	84.3
Landscape Metrics				
Shannon's diversity Index	1.2	1.1	1.4	1.3
Simpson's diversity index	0.61	0.60	0.63	0.60
Patch richness	6.5	5.7	7.6	6.9
Patch richness density	28.3	52.6	11.3	21.3
Patch density	55.1	80.6	37.7	49.9
Shannon's entropy	1.8	1.6	2.0	1.8
Mutual information	0.90	0.76	1.1	0.90
Number of patches	**65.3**	31.8	**140.6**	69.0
Total edge	**25,861.3**	10,628.8	**59,244.0**	27,138.0
Edge density	112.1	121.1	111.2	121.4
Shannon's evenness	0.70	0.69	0.68	0.67

Table 6. Landscape metric comparison between males and females at the home range scale during the breeding season in New York State. The P-values were calculated using a Mann-Whitney U test. Bolded landscape metrics indicate significant differences at P = 0.05.

Landscape Metric	P-value
Shannon's diversity index	0.273
Simpson's diversity index	0.604
Patch richness	0.253
Patch richness density	0.062
Patch density	0.316
Shannon's entropy	0.283
Mutual information	0.179
Number of patches	**0.040**
Total edge	**0.055**
Edge density	0.953
Shannon's eveness	0.697

Table 7. Landscape metric comparison between males and females at the core area scale during the breeding season in New York State. The P-values were calculated using a Mann-Whitney U test. Bolded landscape metrics indicate significant differences at P = 0.05.

Landscape Metric	P-value
Shannon's diversity index	0.248
Simpson's diversity index	0.517
Patch richness	0.093
Patch richness density	0.079
Patch density	0.168
Shannon's entropy	0.305
Mutual information	0.390
Number of patches	0.077
Total edge	0.061
Edge density	0.814
Shannon's evenness	0.646

Table 8. Summaries of male and female territory sizes at the home range and core area scales during the breeding season in New York State. Includes the average, median, standard error (SE), maximum (Max), and minimum (Min).

	Female		Male	
	Home range	Core area	Home range	Core area
Average	112.2	297.6	225.5	541.7
Median	19.2	50.1	123.4	308.5
SE	38.2	105.2	63.6	144.4
Max	761.4	2,241.4	1,033.2	2,232.7
Min	0.5	1.5	2.4	6.4

Figures

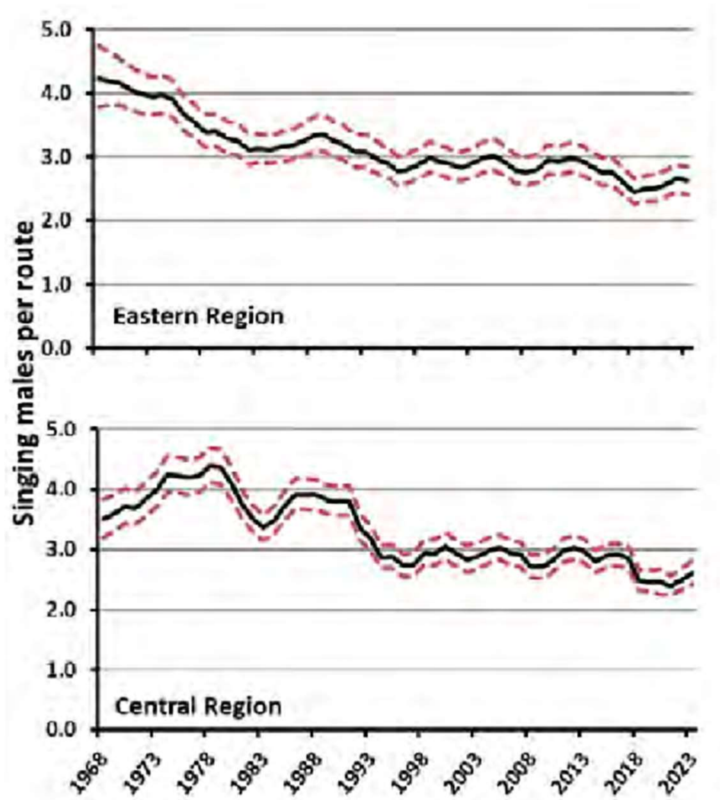

Figure 1. Annual indices of the number of woodcock heard during the Singing-Ground Survey, 1968-2023, as estimated using hierarchical modeling. The red dashed lines represent the 95% credible interval for the estimate. The central and eastern regions are described as distinct management regions within the woodcock range. Taken from the American Woodcock Population Status, 2023 (Seamans and Rau 2023).

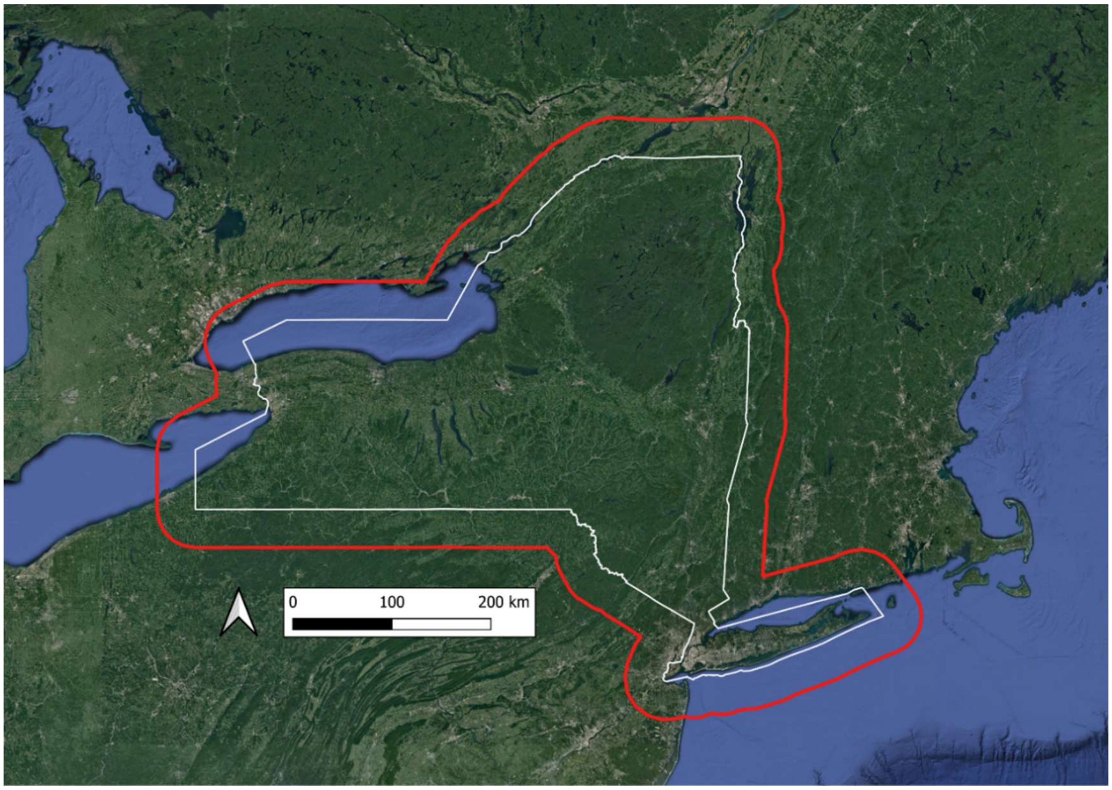

Figure 2. Map of the study area, New York State (white), with an additional 50km buffer (red) placed around the state border. The map is over aerial imagery provided by Google Maps.

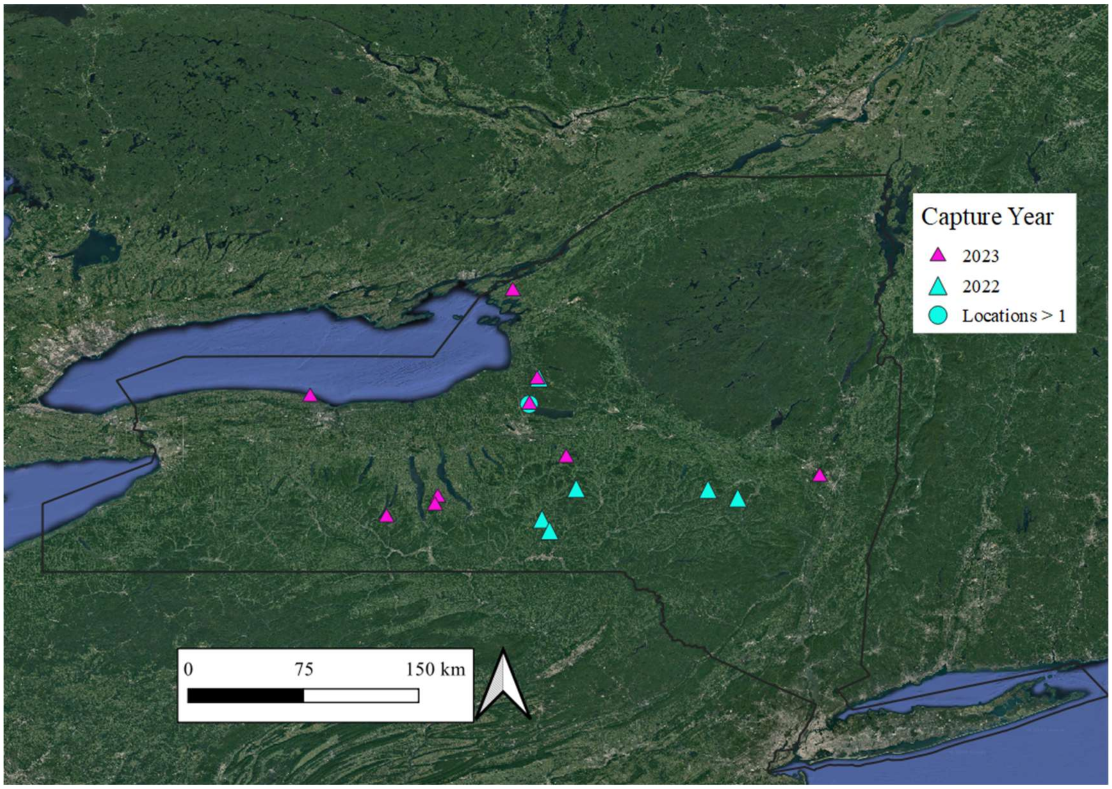

Figure 3. Locations of American woodcock capture locations by year (2022-2023) within New York State over satellite imagery. Teal triangles represent capture locations in 2022, and pink triangles represent capture locations in 2023. Triangles represent locations where a single bird was captured, and circles represent locations where multiple birds (>1) were captured.

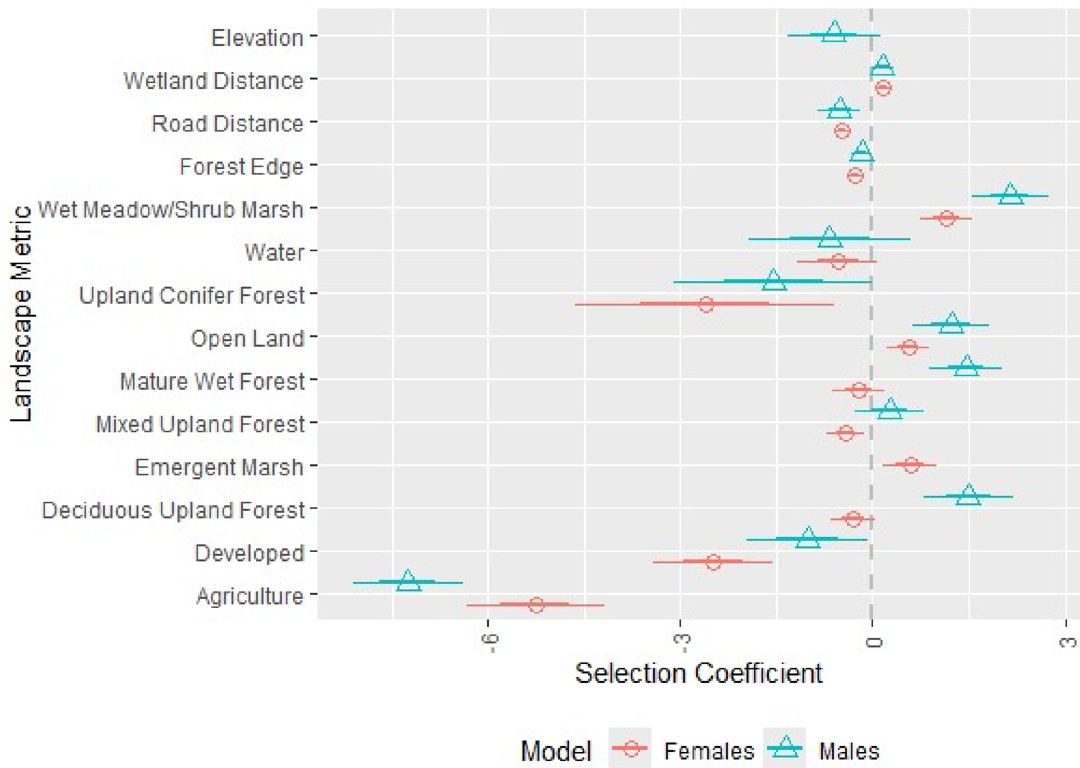

Figure 4. A comparison of male and female woodcock selection coefficients during the breeding season (May 15 – October 15) in New York. Coefficients greater than zero indicate selection for the landscape characteristic. Coefficients less than zero indicate selection against the landscape characteristic. Coefficients at or crossing zero indicate no selection in either direction for the landscape characteristic.

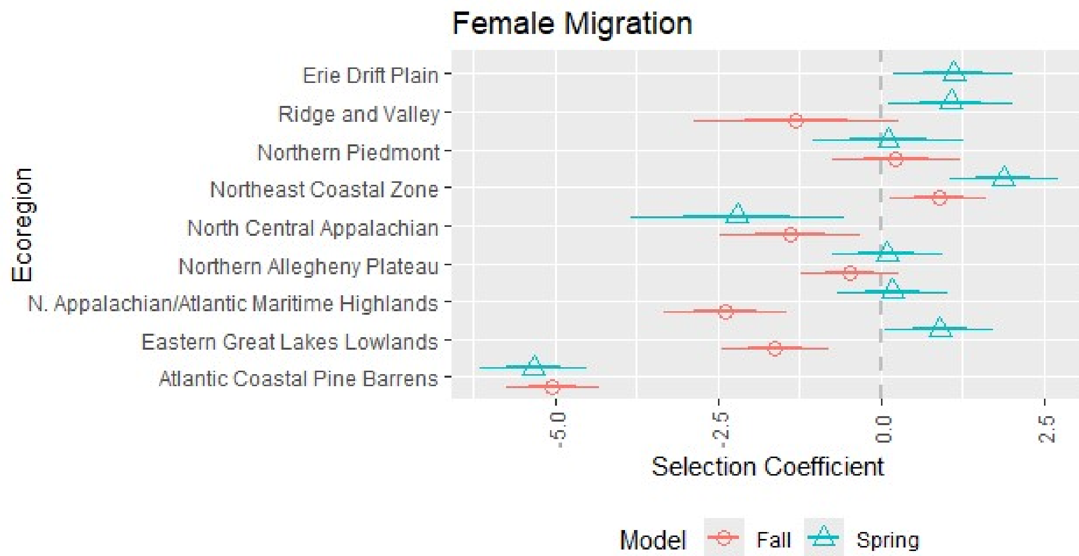

Figure 5. A comparison of female woodcock selection during fall and spring migrations. Coefficients greater than zero indicate selection for the landscape characteristic. Coefficients less than zero indicate selection against the landscape characteristic. Coefficients at or crossing zero indicate no selection in either direction for the landscape characteristic.

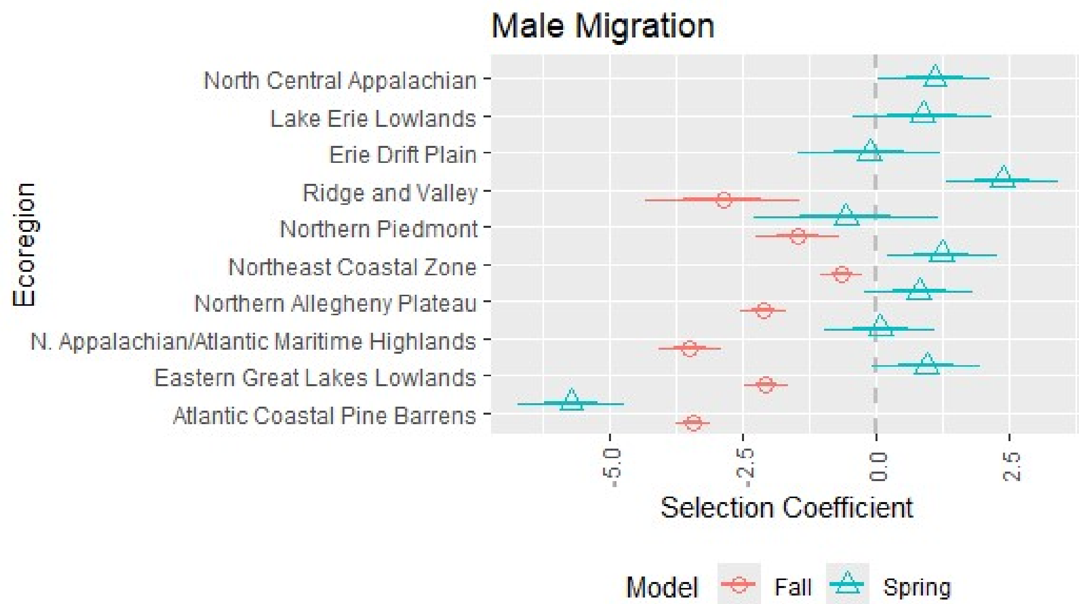

Figure 6. A comparison of male woodcock selection during fall and spring migrations. Coefficients greater than zero indicate selection for the landscape characteristic. Coefficients less than zero indicate selection against the landscape characteristic. Coefficients at or crossing zero indicate no selection in either direction for the landscape characteristic.

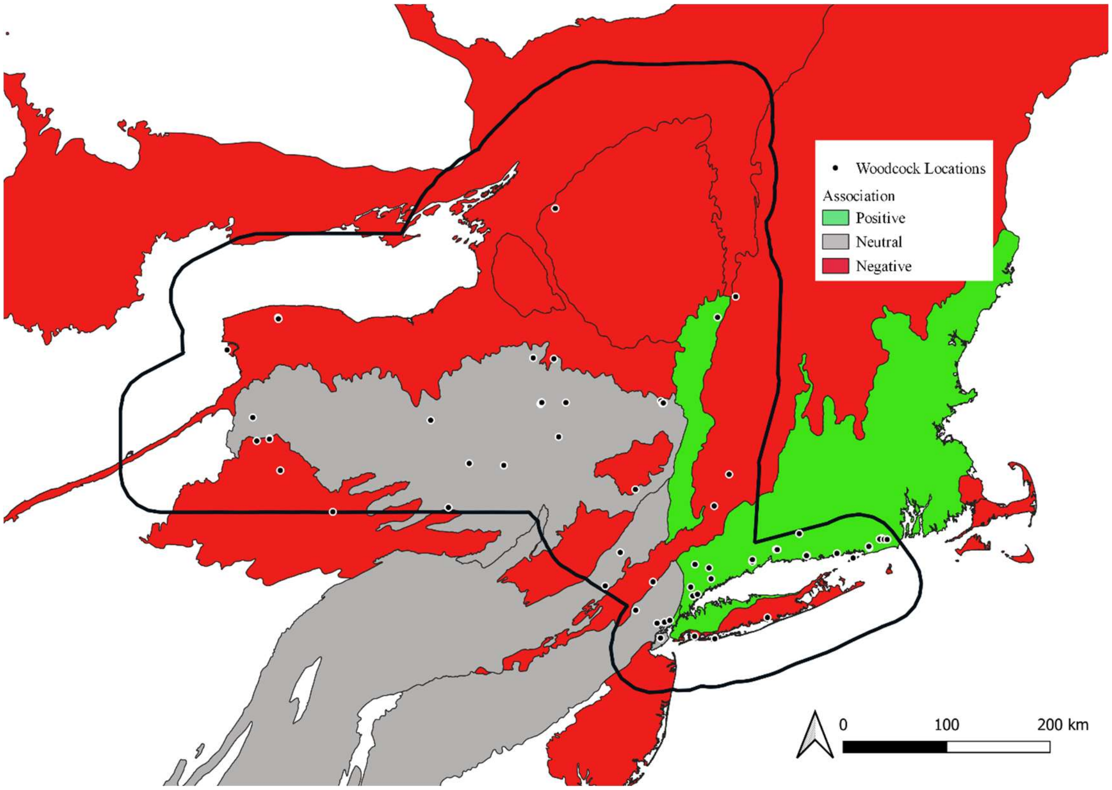

Figure 7. Locations and selection of Environmental Protection Agency Ecozones (Level III) during fall migratory movements of female American woodcock in New York State. Green areas represent ecozones birds selected for, red areas represent ecozones birds selected against, grey areas represent ecozones birds used but did not show selection in either direction, and white areas represent ecozones where birds did not use.

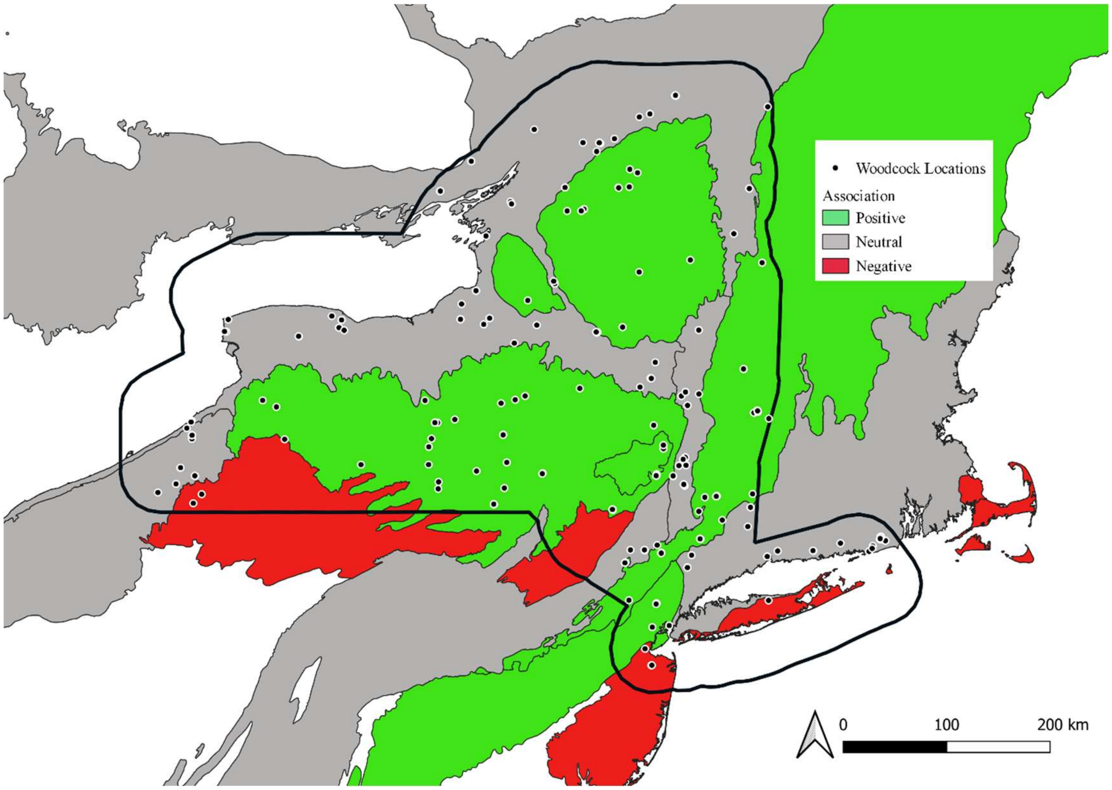

Figure 8. Locations and selection of Environmental Protection Agency Ecozones (Level III) during spring migratory movements of female American woodcock in New York State. Green areas represent ecozones birds selected for, red areas represent ecozones birds selected against, grey areas represent ecozones birds used but did not show selection in either direction, and white areas represent ecozones where birds did not use.

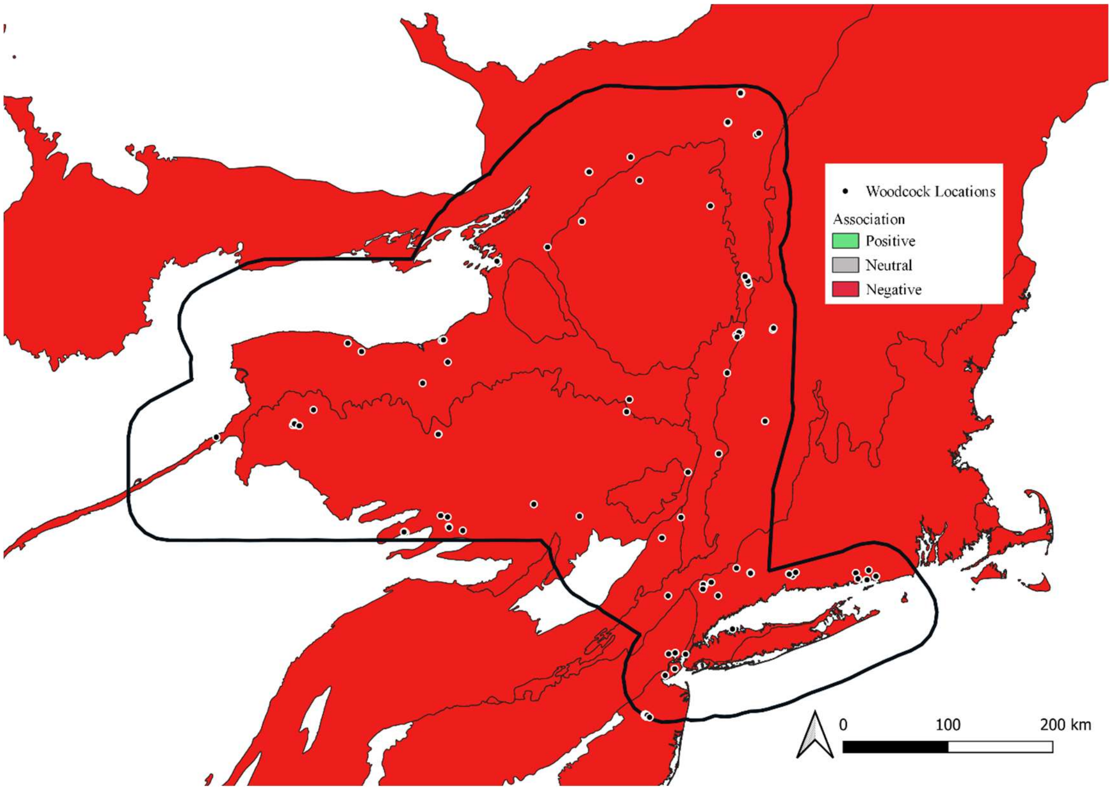

Figure 9. Locations and selection of Environmental Protection Agency Ecozones (Level III) during fall migratory movements of male American woodcock in New York State. Green areas represent ecozones birds selected for, red areas represent ecozones birds selected against, grey areas represent ecozones birds used but did not show selection in either direction, and white areas represent ecozones where birds did not use.

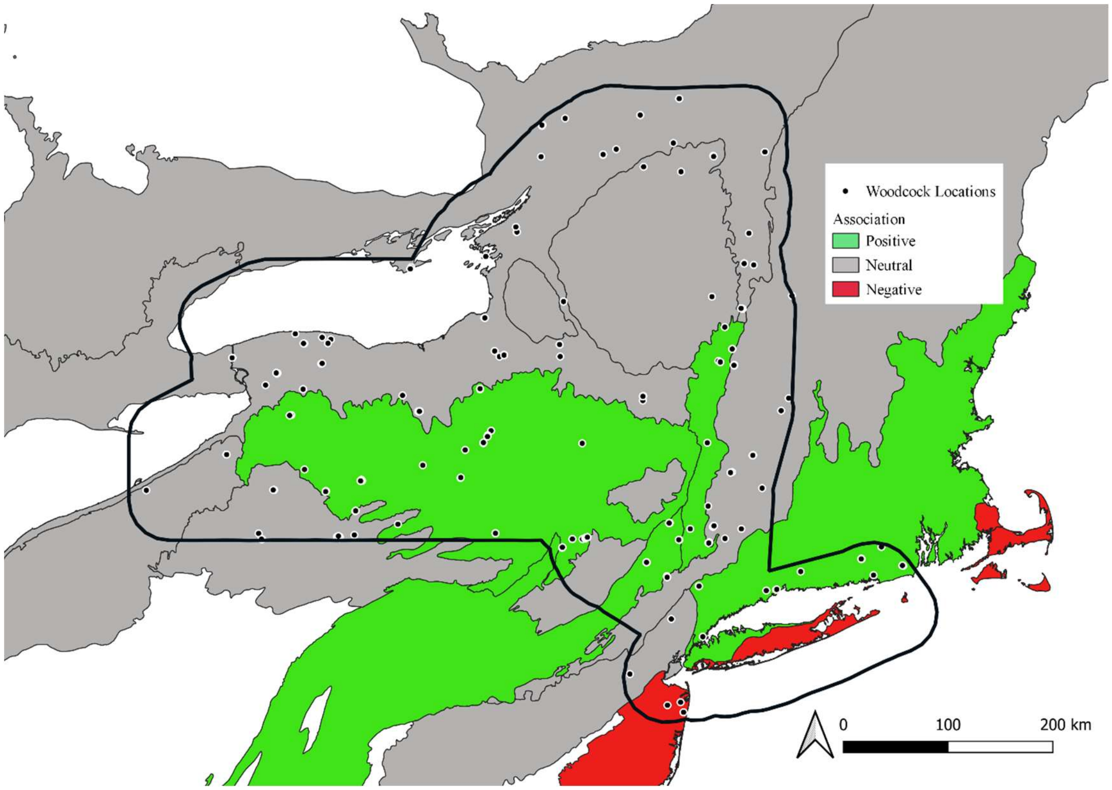

Figure 10. Locations and selection of Environmental Protection Agency Ecozones (Level III) during spring migratory movements of male American woodcock in New York State. Green areas represent ecozones birds selected for, red areas represent ecozones birds selected against, grey areas represent ecozones birds used but did not show selection in either direction, and white areas represent ecozones where birds did not use.

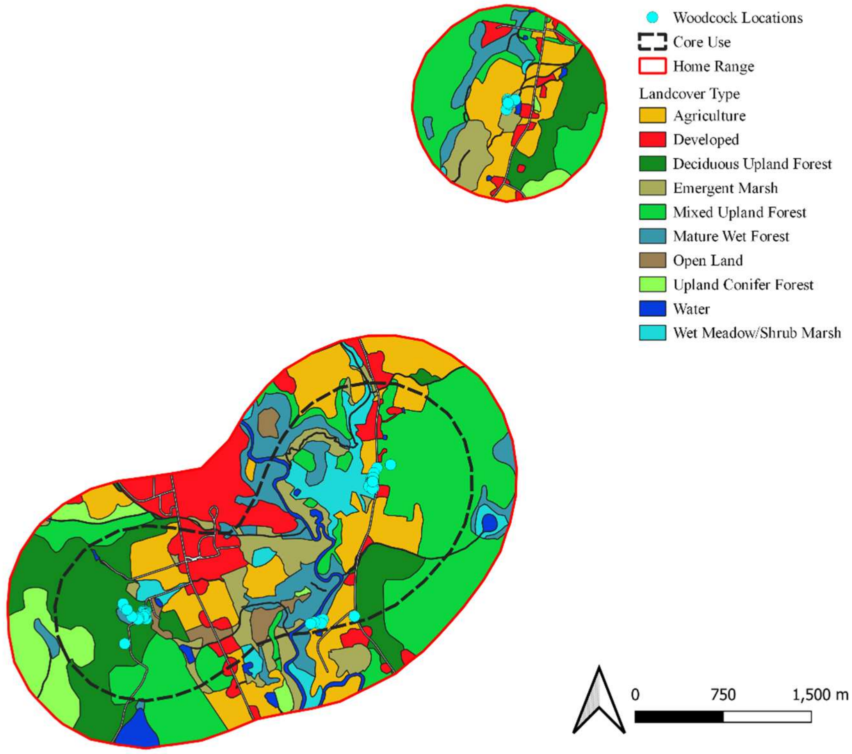

Figure 11. Example of a bird home range (1205 ha, outlined in red) and core use area (516 ha, dashed black line) during the breeding season. The background layer is the digitized landcover layer created from the Nature Conservancy Terrestrial Habitat map and National Wetlands Inventory map. This home range contains all 10 landcover types included in this layer.

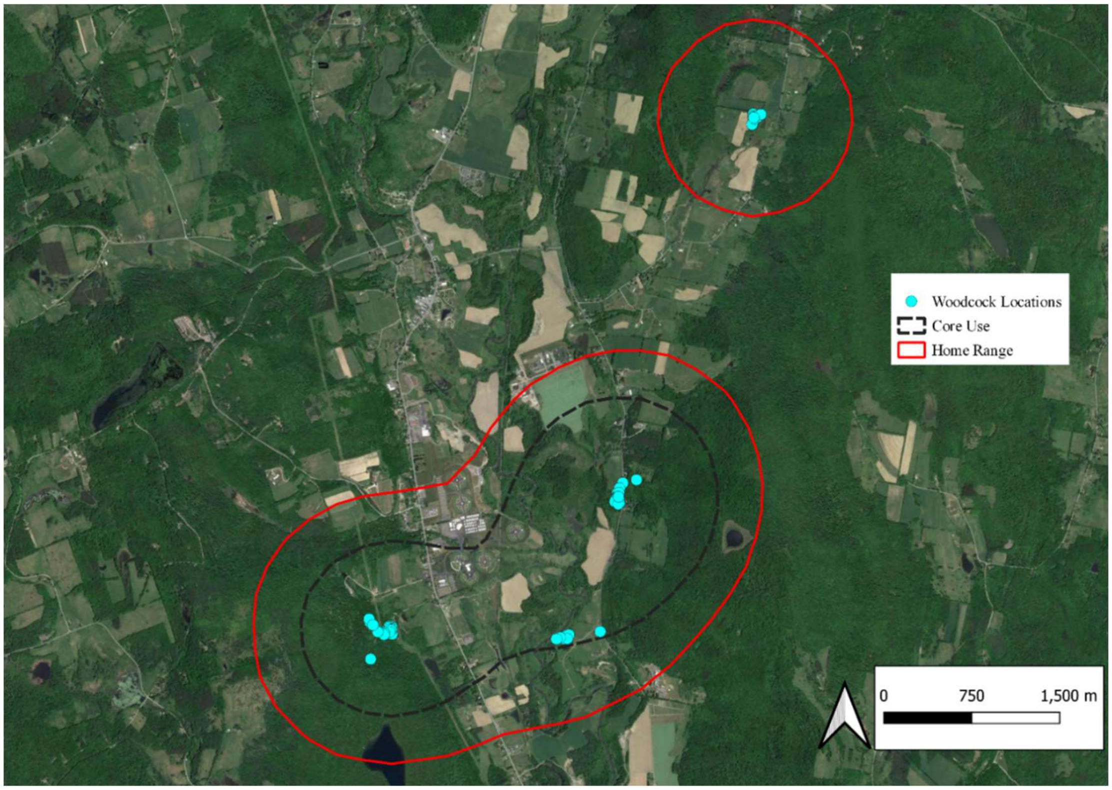

Figure 12. Example of a bird home range (1205 ha, outlined in red) and core use area (516 ha, dashed black line) during the breeding season. The background layer is the aerial imagery provided by Google Maps.

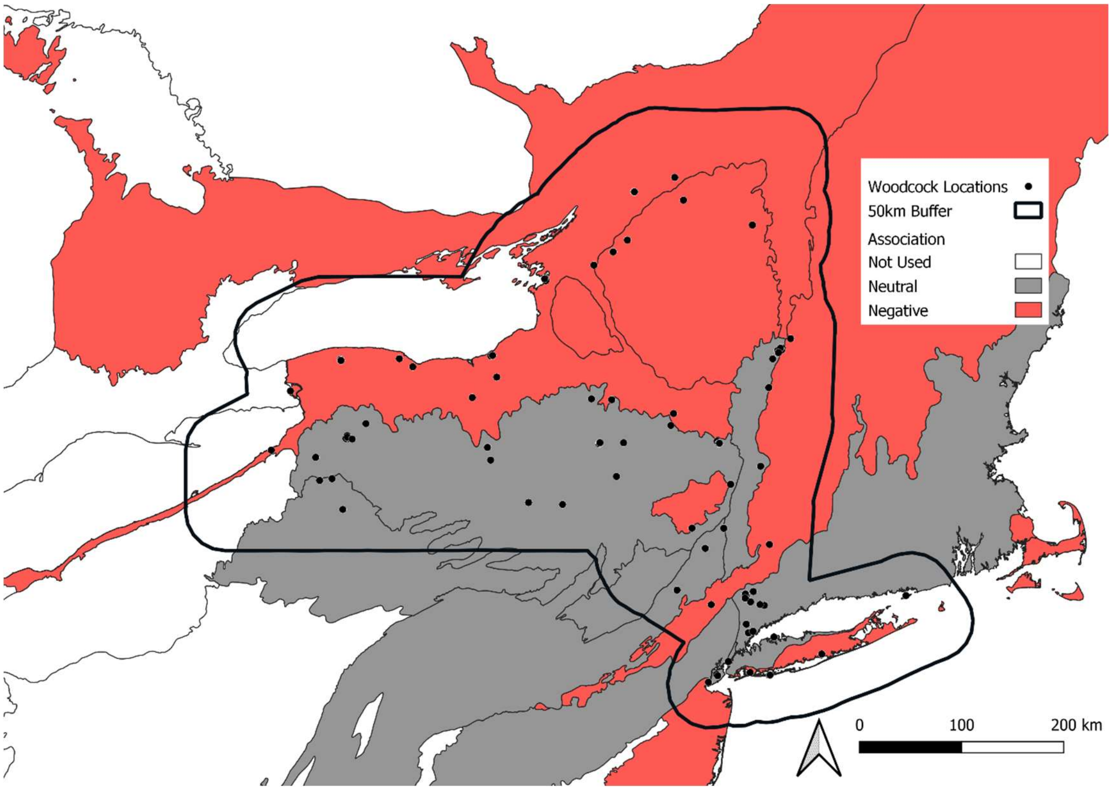

Figure 13. Environmental Protection Agency Ecoregion (Level III) selection during fall migration of all woodcock regardless of sex (n = 210) within New York State. Red areas indicate selection against the ecoregion, grey indicates the ecoregion was used in proportion to what was available, and white indicates an ecoregion was not used at all.

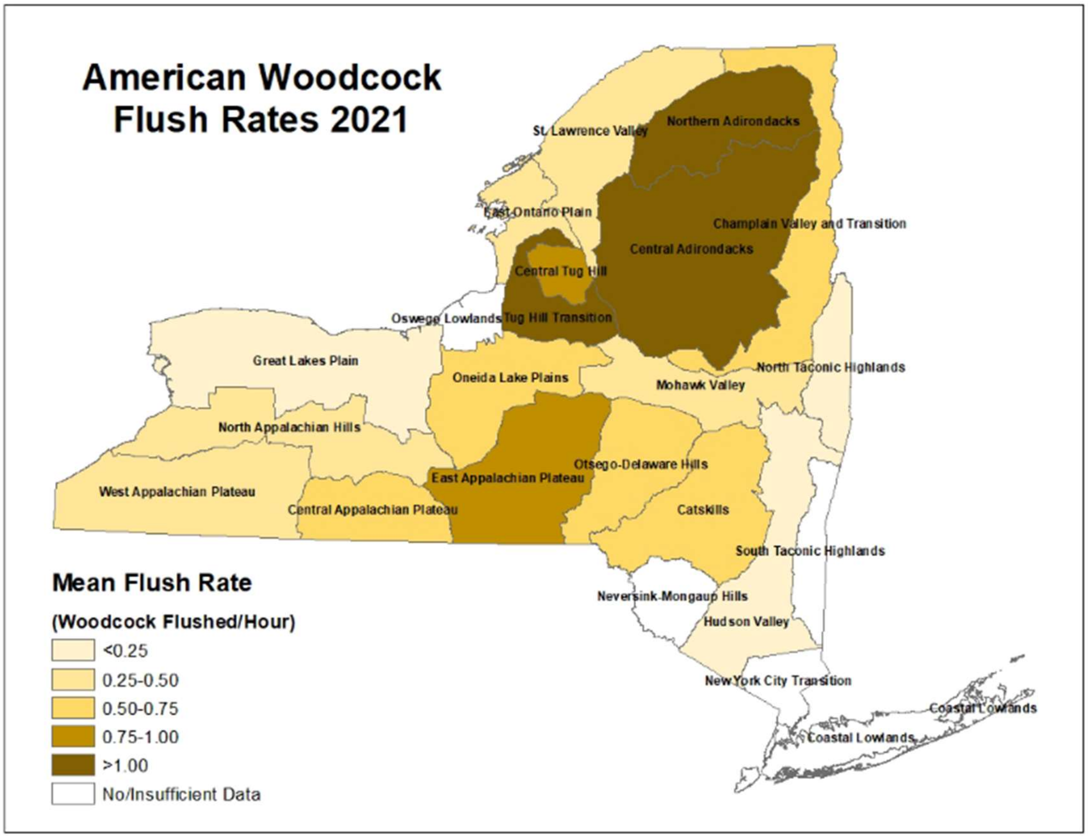

Figure 14. American woodcock flush rate (birds flushed/hour) by Wildlife Management Unit (WMU) aggregate from the Cooperator Ruffed Grouse and American Woodcock Hunting Log, 2021-22. The statewide flush rate for 2021 was 0.66 woodcock flushed/hour. The Coastal Lowlands aggregate does not have a grouse hunting season, so the survey was not conducted there. Image and caption was taken from the NYSDEC Cooperator Ruffed Grouse and American Woodcock Hunting Log 2021-22 (NYSDEC 2022).

Appendix

Appendix 1. The bird identification (ID), sex, first and last location dates, number of locations, home range area (ha), and core area (ha) of all American woodcock (*Scolopax minor*) used in the breeding season analyses. Only locations used in the analyses were included in this table; any outside the breeding season window (May 15 – October 15) or home range were removed.

		Location date			Size of area (ha)	
ID	Sex	First	Last	# of locations	Home range	Core
AL-2-21-10	F	5/15/2021	9/8/2021	36	548.7	203.0
NC-2019-04	F	5/15/2019	10/14/2019	73	1,205.4	516.3
NC-2020-15	F	5/15/2020	10/14/2020	69	2,241.4	761.4
NC-2022-39	F	5/22/2022	6/29/2022	14	1.5	0.6
NY-2019-10	F	9/19/2019	10/15/2019	6*	183.6	73.5
NY-2019-10	F	5/15/2020	6/14/2020	16*	183.6	73.5
NY-2019-11	F	9/20/2019	10/15/2019	7	5.1	2.4
NY-2019-12	F	5/15/2020	6/2/2020	10	3.3	1.2
NY-2019-19	F	9/24/2019	10/15/2019	5	612.4	277.6
NY-2022-38	F	5/15/2022	10/15/2022	53	41.4	17.9
NY-2022-39	F	5/15/2022	10/12/2022	49	41.3	14.2
NY-2022-41	F	5/15/2022	10/15/2022	57	55.6	19.6
NY-2022-42	F	6/7/2022	9/4/2022	35	44.5	18.8
NY-2022-43	F	5/15/2022	10/2/2022	52	652.2	241.6
NY-2022-44	F	5/15/2022	10/15/2022	59	345.1	130.3
NY-2022-45	F	5/15/2022	10/15/2022	59	26.5	9.7
NY-2022-47	F	5/15/2022	9/30/2022	55	19.2	7.2
NY-2023-48	F	5/16/2023	7/9/2023	31	4.0	1.8
NY-2023-49	F	5/15/2023	7/20/2023	34	628.9	227.2
NY-2023-55	F	6/1/2023	7/18/2023	17	283.9	94.1
NY-2023-56	F	6/3/2023	7/27/2023	29	107.7	39.0
SC-2019-04	F	5/15/2019	10/4/2019	52	5.4	1.7
SC-2022-25	F	5/16/2022	8/24/2022	23	8.4	2.7
VA-2020-83	F	5/17/2021	7/29/2021	20	13.8	5.7
VT-2020-11	F	9/18/2020	10/15/2020	8	64.3	26.0
AL-2022-20	M	5/16/2022	8/5/2022	6	751.5	262.3

Appendix 1 (*continued*)

		Location date			Size of area (ha)	
ID	Sex	First	Last	# of locations	Home range	Core
GA-2021-16	M	5/18/2021	7/26/2021	12	134.1	49.2
MD-2019-05	M	5/18/2019	10/5/2019	31	295.3	107.7
NY-2018-04	M	9/24/2018	10/15/2018	5	19.2	7.1
NY-2018-05	M	9/24/2018	10/15/2018	5	15.5	5.6
NY-2023-50	M	5/16/2023	7/28/2023	43	1,242.70	520.1
NY-2023-51	M	5/17/2023	7/28/2023	34	25.9	7.9
NY-2023-52	M	5/25/2023	7/22/2023	30	219	87.5
NY-2023-53	M	5/25/2023	7/28/2023	35	400.7	168.5
PA-2020-25	M	5/16/2021	7/15/2021	11	6.4	2.4
RI-2018-01	M	9/4/2018	10/13/2018	6	389.6	181.9
RI-2018-13	M	9/13/2018	10/13/2018	7	385.2	139.1
SC-2020-17	M	5/23/2020	10/9/2020	29	321.7	141.1
VA-2019-11	M	5/16/2019	10/2/2019	24	221.3	88.8
VA-2020-52	M	6/28/2020	10/11/2020	20	976.8	348.2
VA-2020-78	M	5/18/2021	7/27/2021	13	1,955.50	808.3
VT-2020-05	M	9/17/2020	10/15/2020	8	2,232.70	1,033.20
VT-2020-09	M	9/17/2020	10/15/2020	7	1,058.70	488.7

*This bird had locations from 2019 and 2020 in the same area. Locations were combined to 1 home range.

Appendix 2. Global positioning system (GPS) tag identification number (ID), deployment date, New York State Department of Environmental Conservation (DEC) Region of deployment, latitude, longitude, and capture method of all American woodcock captured in New York State in 2022 and 2023.

GPS Tag ID	Deployment Date	DEC Region	Latitude	Longitude	Capture Method
229377	4/26/2022	7	42.39913	-75.97223	FLIR/Spotlight/Hand Net
229374	4/27/2022	6,7	43.47043	-75.99487	FLIR/Spotlight/Net
229379	4/28/2022	8	43.09604	-78.45353	Spotlight/Hand Net
229371	5/2/2022	4	42.624117	-74.711879	FLIR/ Spotlight/ Hand Net
229376	5/3/2022	7	42.63146	-75.71238	FLIR/ Spotlight/ Hand Net
229372	5/3/2022	4	42.55958	-74.48634	FLIR/ Spotlight/ Hand Net
229375	5/4/2022	7	42.31145	-75.91438	FLIR/Spotlight/Hand Net
229373	5/5/2022	6,7	43.27089	-76.06981	FLIR/Spotlight/Hand Net
229374	5/5/2022	6,7	43.26966	-76.06796	FLIR/Spotlight/Hand Net
229380	5/11/2022	6,7	43.26721	-76.06202	FLIR/ Spotlight/ Hand Net
229378	5/11/2022	6,7	43.26133	-76.05187	FLIR/ Spotlight/ Hand Net
239528	5/2/2023	7	42.8634	-75.78812	FLIR/Spotlight/Hand Net
239532	4/20/2023	6	43.45927	-76.00797	FLIR/Spotlight/Hand Net
239534	5/9/2023	8	43.431659	-77.728252	FLIR/Spotlight/Mist Net
239535	5/12/2023	8	42.41124	-77.15172	Mist Net
238529	5/15/2023	6,7	43.2677	-76.06685	Mist Net
239527	5/18/2023	4	42.719715	-73.864212	Mist Net
238006	5/18/2023	4	42.719662	-73.864344	Mist Net
239536	5/18/2023	8	42.562216	-76.762458	Mist Net
239530	6/1/2023	8	42.501862	-76.784331	Hand Net
239533	6/6/2023	6	44.1288	-76.193393	Mist Net

Appendix 3. The number of woodcock tagged per state or province that were used in the migration analyses. Numbers are broken down by males and females and which analysis they were in; spring or fall migration. Woodcock were tagged between 2017 – 2023.

	Female Fall	Female Spring	Male Fall	Male Spring
Alabama	0	2	0	6
Florida	0	0	0	13
Georgia	0	66	0	24
Louisiana	0	0	0	3
Maryland	0	107	0	62
Maine	45	2	49	1
North Carolina	1	74	1	186
Nova Scotia	3	0	19	0
New Jersey	0	102	0	48
New York	29	42	22	0
Pennsylvania	0	16	23	1
Quebec	41	13	74	9
Rhode Island	35	88	5	14
South Carolina	0	7	4	48
Virginia	1	76	6	32
Vermont	38	6	70	14
Total	193	601	273	461