Assessment of Techniques for Evaluating American Woodcock Population Response to Best Management Practices Applied at the Demonstration-Area Scale[1]

2013 Annual Report

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Abstract: American woodcock (*Scolopax minor)* have experienced significant long-term population declines in the Eastern and Central Management Regions since Singing-ground Surveys (SGS) were first implemented in the mid-1960s. Declines in population trend coupled with declines in woodcock recruitment are widely believed to be caused by the loss or alteration of early succession forest and shrubland land-cover types throughout the breeding range. Developing a system of demonstrations areas (~200 – 800 ha) where specific Best Management Practices (BMPs) are applied throughout the woodcock breeding range is one strategy to influence landscape change and potentially increase woodcock population size. However, how woodcock populations respond to BMPs applied at the demonstration-area scale is not well documented. To evaluate woodcock response to BMPs, we are assessing four population-level metrics at Tamarac National Wildlife Refuge (NWR) in northwest Minnesota: displaying male abundance, female habitat use, female survival, and recruitment of juveniles. During the 2011 and 2012 field seasons we captured a total of 529 woodcock, including 41 (2011: *n* = 23, 2012: *n* = 18) adult female woodcock that we radio-marked. We found 50 nests (2011: *n* = 27, 2012: *n* = 23) and monitored 52 woodcock broods (2011: *n* = 30, 2012: *n* = 22). In 2011, abundance of displaying males was similar at Tamarac NWR to abundance in adjacent, reference areas, but in 2012 Tamarac NWR had higher abundance than adjacent areas. In both years, breeding females and broods used dense vegetation in managed areas.

INTRODUCTION

American woodcock (*Scolopax minor)* have experienced significant long-term population declines in the Eastern and Central Management Regions (−0.98% and −0.80% per year respectively) since Singing-ground Surveys (SGS) were first implemented in 1968 (Cooper and Rau 2013). The most recent 10-year trend (2003-2013) remained stable in both the Eastern and Central Management Regions, suggesting that woodcock population soze may be stabilizing, but may also not be increasing toward U.S. Fish and Wildlife Service population goals (Cooper and Rau 2013). These apparent declines in population size are coupled with declines in woodcock recruitment across their range (indexed through immature:adult female ratios derived from wing-collection surveys; Cooper and Rau 2013). Extensive loss or alteration of habitat critical to woodcock reproduction has been suggested as the main cause of these declines (Dwyer et al. 1988, Gregg 1984, Sauer and Bortner 1991, Kelly et al. 2008). However, trends in woodcock abundance, based on SGS counts, have remained stationary in Minnesota for the period covered by the SGS (1968 – 2013, Cooper and Rau 2013), even though the amount of land-cover types important to American woodcock has increased from historic conditions in the Minnesota portion of Bird Conservation Region 12 (BCR12; Kelley et al. 2008).

To stabilize and ultimately increase size of woodcock populations, a system of habitat demonstration areas is being developed where specific Best Management Practices (BMPs) are applied throughout the woodcock breeding range (Wildlife Management Institute 2010). Application of BMPs at a demonstration-area scale (~200–800 ha) is designed to positively influence woodcock population growth by improving habitat quality at a landscape scale. BMPs create or maintain young forest cover through clear-cutting, timber harvest, shearing of brush and small trees, and prescribed burning (Wildlife Management Institute 2009). BMPs are applied at specific sites within the larger landscape, but when applied at multiple locations at the demonstration-area scale, they create a juxtaposed mosaic of young forest cover of different age classes that provides breeding, nesting, brood-rearing, and diurnal feeding habitat for woodcock. Woodcock are known to numerically respond to management (Dwyer et al. 1988, McAuley et al. 1996); therefore, it is assumed that increasing the amount of young forest cover at the demonstration-area scale will increase woodcock population size. In collaboration with cooperators in two other study areas (Fig. 1), we are assessing woodcock population responses to BMPs applied at the demonstration-area scale by focusing on four metrics: displaying male abundance, female habitat use and survival, and recruitment. However, techniques for evaluating these responses have not been fully assessed. To evaluate woodcock population responses at other areas where BMPs are applied in the future, it is necessary to first assess the efficacy of techniques to describe male and female woodcock habitat use and estimate vital rates.

Our objectives are to assess techniques to describe male and female woodcock habitat use and estimate vital rates at three existing demonstration areas; Tamarac National Wildlife Refuge (NWR) in Minnesota, Moosehorn NWR in Maine, and Lyme Timber Company Land in New York. Tamarac NWR is a demonstration area within the Upper Great Lakes and Young Forest Initiative (UGLYFI) coordinated by the Wildlife Management Institute. The UGLYFI is modeled after the Northern Young Forest Initiative (NYFI), for which Moosehorn NWR and the Lyme Timber Company Land are demonstration areas (Fig. 1). The UGLYFI and NFWI are aimed at increasing abundance of woodcock and other species of concern (i.e., golden-winged warbler [*Vermivora chrysoptera*], eastern towhee [*Pipilo erythrophthalmus*], black-billed cuckoo [*Coccyzus erythropthalmus*], etc.) that depend on early successional forest land cover. A primary strategy within both these initiatives is the development of a set of BMPs (e.g., Wildlife Management Institute 2009), including application of BMPs at demonstration areas, which will guide habitat management efforts on designated public and private lands.

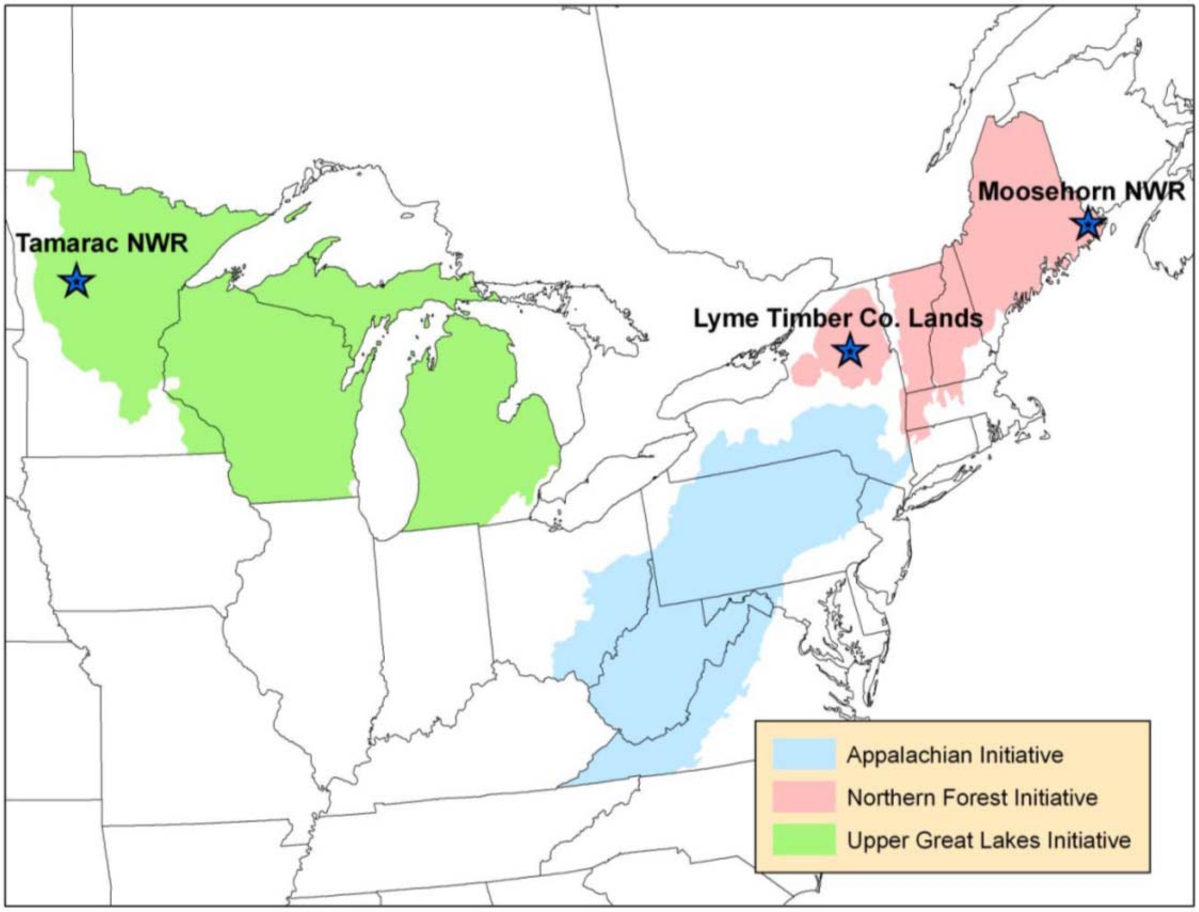

Figure 1. Location of regional American woodcock initiatives and study areas (indicated by blue stars).

The goals of our project are to describe male and female habitat use and estimate baseline demographic parameters for woodcock at demonstration areas and to assess techniques for measuring woodcock response to habitat management at the demonstration-area scale.

Our specific objectives are:

1) Assess response of displaying male American woodcock to BMPs at the demonstration-area scale by comparing abundance of displaying male American woodcock on three demonstration areas with abundance in the surrounding landscape, as measured by routes that are part of the American Woodcock SGS.

2) Evaluate radio-telemetry as a tool to measure female woodcock response to application of BMPs at the demonstration-area scale.
3) Estimate adult female survival, nest success, and brood survival and relate these parameters to habitat variables at each demonstration site.
4) Estimate recruitment using night-lighting and mist-net capture techniques on summer roosting fields at demonstration areas, and evaluate these techniques as a means to assess recruitment.
5) Develop and assess techniques for radio-marking American woodcock juveniles to estimate juvenile survival and document brood habitat use.

STUDY AREAS

This project is being conducted at three study sites, Tamarac NWR located in western Minnesota, Lyme Timber Company land in northeastern New York, and Moosehorn NWR in northern Maine (Fig.1). All three of these sites currently participate in regional woodcock initiatives and contain demonstration areas where BMPs have been applied, or are being incorporated into management. In addition, these three locations represent different breeding habitats that occur across the woodcock breeding range.

Tamarac NWR:--Tamarac NWR was established in 1938 to protect, conserve, and improve breeding grounds for migratory birds. It lies in the glacial lake country of northwestern Minnesota in Becker County, 97 km east of Fargo, North Dakota and encompasses 17,296 ha (42,738 acres) of rolling forested hills interspersed with lakes, rivers, marshes, and shrub swamps. Vegetation is diverse due to the refuge's location in the transition zone between the coniferous forest, northern hardwood forest, and tall-grass prairie. Sixty percent of the refuge is forested, consisting of aspen (*Populus* spp.), jack pine (*Pinus banksiana*), red pine (*P. resinosa*), balsam fir (*Abies balsamea*), paper birch (*Betula papyrifera*), red oak (*Quercus rubra*), white oak (*Q. alba*), sugar maple (*Acer saccharum*), and basswood (*Tilia americana*) cover types. The refuge lies near the western edge of the American woodcock breeding range in North

America. Timber harvest and prescribed fire programs on the refuge have sustained early successional forest cover, which is primary breeding, nesting, and brood-rearing habitat for American woodcock.

Prior to settlement by people of European decent, much of the landscape at Tamarac NWR was dominated by red, jack, and white pine (*Pinus strobus*) cover types. Extensive logging of red and white pine occurred on the refuge from 1890-1910, converting much of the coniferous forest to an aspen cover type. Prior to 1987, limited harvest of aspen occurred on Tamarac NWR due to poor aspen markets in Minnesota (approximately 60 ha were harvested per year for all forest cover types combined); therefore many of the aspen-dominated stands were slowly succeeding to other cover types. Markets for aspen improved in the late 1980s and from 1987 to 1990, approximately 350 ha of aspen were harvested annually. Since 1990, the average annual harvest of aspen has been approximately 50 ha. Although the accelerated timber harvest program in the late 1980s quickly tapered off in the early 1990s, much of the refuge was still managed for early successional habitats, such as young, regenerating aspen. A hydroaxe, or large brush mower, was used to maintain some of these cut-over aspen sites through the 1990s.

Moosehorn NWR:--Moosehorn NWR in eastern Maine was established in 1937 as a refuge for migratory birds, with particular emphasis on American woodcock. The refuge consists of two divisions, which are approximately 32 km apart; the Baring Division and the Edmunds Division. The Baring Division is 8,136 ha (20,096 acres) and is located southwest of the city of Calais, on the international border with New Brunswick, Canada. The Edmunds Division is 3,562 ha (8,799 acres) and is located to the south of the Baring Division, between the towns of Dennysville and Whiting. Farming, logging, and wildfire affected the uplands of Moosehorn prior to the 1900s; however, as the timber supplied by these lands declined, many farms that were tied to the logging industry were abandoned and came under ownership of the federal Re-Settlement Administration (Weik 2010). These abandoned farmlands eventually succeeded into young, second-growth forests, which provided high-quality woodcock habitat.

Moosehorn NWR has been the site of intensive woodcock research starting in the 1930s, much of which dealt with population responses to management of habitat to benefit woodcock. Woodcock populations peaked on the refuge in the 1950s; however, forest maturation subsequently led to declines in woodcock densities throughout the refuge. Forest management practices ensued in the 1980s through 2009 to improve woodcock habitat, add diversity to the age-structure of the forests, and achieve economic benefit from timber harvest (Weik 2010). American woodcock research and monitoring continue on the refuge.

Forests cover 90% of present day Moosehorn NWR. Species composition varies from nearly pure spruce-fir (*Picea* spp.-*Abies* spp.) stands to hardwood mixtures of aspen, paper birch, red maple (*Acer rubrum*), red oak, and beech (*Fagus grandifolia*) with interspersed white pine. Alder (*Alnus* spp.) stands are also common along streams and abandoned fields. The landscape of Moosehorn NWR also contains natural and human-made water bodies, meadows, and managed blueberry (*Vaccinium* spp.) fields (Weik 2010).

Lyme Timber Company:--Lyme Timber Company is a private timberland investment management organization dedicated to the acquisition and sustainable management of land with unique conservation value. Since the company was founded in 1976, Lyme has acquired and managed forestland and rural real estate across the eastern U.S. (Lyme Timber Company 2010). Currently, Lyme manages 180,490 ha (446,000 acres) of forestland located in New York, Pennsylvania, Maine, Massachusetts, Tennessee, Virginia, Delaware, and Louisiana.

The Lyme Timber Company owns and manages the Lyme Adirondack Forest Company (LAFCo) in upstate New York. The LAFCo consists of the largest extent of private forestland in New York, including 20 blocks of forests, totaling approximately 112,503 ha (278,000 acres). All lands owned and managed by the LAFCo are contained within Adirondack Park, which is located in northern New York within Clinton, Essex, Franklin, Fulton, Hamilton, Herkimer, Lewis, Oneida, Saint Lawrence, Saratoga, Warren, and Washington counties.

LAFCo lands are heavily forested with northern hardwoods, spruce, and fir and contain numerous lakes, streams, rivers, and wetlands. Nearly the entirety of Adirondack Park is kept in a “forever wild” state where very little or no logging is allowed, so young forest cover types utilized by woodcock are scarce. Since obtaining the property in 2006, LAFCo has incorporated a management plan to put 5% of each of the 20 blocks within the property into young forest cover types over the next 10 years, increasing the amount of area in young forest cover types from 31 ha (76 acres) to > 4,046 ha (10,000 acres). To date, approximately 898 ha have been converted to young forest cover types (Timberdoodle.org 2010).

METHODS *(by objective)*

1) Assess response of displaying male American woodcock to BMPs at the demonstration-area scale by comparing abundance of displaying male American woodcock on three demonstration areas with abundance in the surrounding landscape, as measured by routes that are part of the American Woodcock SGS.

We accessed data from previously established SGS routes surrounding all three study areas and establish additional survey routes at Tamarac NWR following the American Woodcock SGS protocol (Cooper and Rau 2013). We established survey routes at Tamarac NWR by stratifying the refuge and placing new routes with stops within areas where management has occurred or is occurring and areas where no management has occurred, proportional to the areas of these lands within the refuge landscape. We surveyed routes in Tamarac NWR following the American Woodcock SGS protocol (Cooper and Rau 2013). We compared abundance indices calculated for routes established on Tamarac NWR to indices calculated for SGS routes at varying spatial scales. These included the six closest routes to Tamarac NWR, routes in the state of Minnesota, and routes in the Central Management Region. We used this assessment to compare woodcock population abundance at demonstration areas to abundance in the surrounding landscape, and to evaluate population-level response of displaying male woodcock to management.

2) Evaluate radio-telemetry as a tool to measure female woodcock response to application of BMPs at the demonstration-area scale.

We captured and placed transmitters on female woodcock at Tamarac NWR throughout the breeding seasons in 2011 and 2013. We primarily used mist nets to capture females; however, we also used pointing dogs and hand nets, beginning as soon as they arrived on the study area in the spring. We fit all captured females with a radio transmitter weighing < 3% of the bird's mass (McAuley et al. 1993a). This method of attaching radio transmitters has been documented to have no discernable effects on female woodcock behavior (McAuley et al. 1993b). After radio marking, we located females regularly (5-7 times per week), but not more than once every 24 hours and assessed their fates (alive, or dead) and breeding status (pre-nesting, nesting, brood rearing, or post-breeding). We recorded date, time, and UTM coordinates (derived using hand-held GPS units) at each location.

3) Estimate adult female survival, nest success, and brood survival and relate these parameters to habitat variables at each demonstration site.

We monitored radio-marked, adult female woodcock at Tamarac NWR regularly (5-7 days per week) throughout the nesting and brood-rearing periods to estimate survival and the ratio of immature woodcock reaching fledging per adult female. The ratio of immature woodcock per adult female provided an estimate of productivity, and is the measure of productivity derived from parts collection surveys by the U.S. Fish and Wildlife Service (Cooper and Rau 2013). To determine nest success and the number of young hatched per successful nest, we monitored nests initiated by radio-marked woodcock at 2-3-day intervals. We also monitored nests found using other methods, primarily the use of pointing dogs, at 2-3 day intervals. We estimated apparent nest survival (number of successful nests/total number of nests). We defined a successful nest as a nest where at least one egg hatched.

To estimate brood survival, we monitored broods of radio-marked females 5-7 times per week. We also used pointing dogs to locate woodcock broods for radio-marking (Ammann 1974). Once located, we captured juveniles using a long-handled dip net. We targeted 2- to 3-day-old juveniles to achieve a sample to estimate survival for the entire period from hatch to fledging, but also captured older juveniles. At capture, we custom fit a collar-type micro-transmitter with a whip antenna to 1-2 chicks per brood. We monitored radio-marked broods 5-7 days per week. We periodically inspected broods for any radio-marking effects by determining whether transmitters were correctly located around the bird's neck and whether the transmitter's antenna was pointing down the bird's back.

We classified birds as either alive or dead each time we located them via radio telemetry. If the bird was dead, we attempted to determine cause of death. Cause of death was classified as depredated or "other" (e.g., starvation, exposure, capture-related). Birds classified as depredated were examined to determine cause of predation, either mammalian or avian (McAuley et al. 2005). Mammalian predators usually remove wings and legs, eat most of the bird (including feathers), and remove the transmitter from the carcass, leaving bite marks on the antenna and harness. Some mammals bury carcasses or carry them to den sites. Raptors typically pluck feathers and remove flesh from bones. Occasionally, raptors leave bill marks on the antenna and harness (McAuley et al. 2005). If we were unable to determine whether a bird was depredated by a mammal or a raptor, we classified the cause of that mortality as unknown predation. We classified a few females and fledged juveniles we monitored as "lost," which occurred when either the bird emigrated from the search area or the radio transmitter slipped from the bird. If birds were classified as lost, we censored them from data analyses. For the purposes of this study, if we were unable to relocate a radio-marked juvenile during the pre-fledging period, we classified it as lost and censored it from data analysis. If we did not relocate a radio-marked chick during the pre-fledging period, but detected the rest of the brood, we classified the radio-marked juvenile as dead.

We recorded each female, brood, and fledged juvenile location with a hand-held GPS unit (Garmin GPSmap 76CSx set to coordinate system: UTM, datum: NAD83). We also recorded nest site locations with the same equipment and settings. We used an average of 100 points to achieve a minimum estimated error at each point.

We used logistic-exposure survival models (Shaffer 2004) to evaluate relationship(s) between weather and individual characteristics and female, nest, and juvenile survival. We also used logistic-exposure models to assess the relationship(s) between vegetative structure and survival of nests and juveniles. We developed *a priori* models to evaluate factors related to adult female, nest, and juvenile survival that incorporated covariates related to hypotheses about effects of weather and individual characteristics of females, nests, and juveniles on survival of adult females, nests, and juveniles (Appendix A). We incorporated covariates relating vegetation structure in *a priori* models for nests and in a post hoc analysis for juveniles. We evaluated models using a stepwise approach in an information-theoretic framework (Burnham and Anderson 2002). We started with an initial model incorporating YEAR for each survival model of females, nests, and juveniles to assess survival differences between 2011 and 2012, and to account for reported differences among years (Longcore et al. 2000). During each step of our modeling process subsequent to the initial model, we added covariates to the best-supported model from the previous step individually and in all combinations and ranked models based on Akaike's Information Criterion adjusted for small sample size (AICc) to identify the best-supported model among all candidate models. We defined our best-supported model as the model with the lowest AICc (ΔAICc =0) and competing models as any models with $\Delta\text{AICc} \leq 2$ of the best-supported model.

From the best-supported model that considered all categories of covariates, we report cumulative survival for woodcock females, nests, and juveniles over relative periods during the breeding season (April 1 to July 31; 122 days for females, April 1 to June 15; 76 days for nests, and May 1 to July 31; 92 days for juveniles) and associated 95% confidence intervals for both 2011 and 2012.

4) Estimate recruitment using night-lighting and mist-net capture techniques on summer roosting fields at demonstration areas, and evaluate these techniques as a means to assess recruitment.

We used night-lighting and mist nets to capture woodcock on summer roost fields (Dwyer et al. 1988). Upon capture, we assigned an age (hatch year or after hatch year) and gender using body measurements and feather characteristics (Martin 1964, Sepik 1994) to all birds. We also calculated immature:adult female capture ratios and compared these estimates of recruitment to one another, and also to an estimate of recruitment derived from wing-collection surveys (Cooper and Rau 2013) and an estimate of recruitment derived from radio-telemetry survival data.

5) Assess techniques for radio-marking American woodcock chicks to estimate juvenile survival.

In early spring of 2011 and 2012 we used mist nets to capture woodcock during crepuscular periods and attached radio-transmitters to adult female woodcock using a glue-on backpack-style harness. We tracked radio-marked female woodcock throughout the breeding, nesting, and brood-rearing periods and estimated survival of unmarked juvenile woodcock from hatching to fledging and also radio-marked a sample of juveniles within broods. During the brood-rearing period, we used trained pointing dogs to find additional broods that we captured and radio-marked.

We custom fit a collar-type micro-transmitter (BD-2NC or BD-2C, Holohil Systems Ltd.) with a whip antenna to captured woodcock chicks. These micro-transmitters are significantly smaller and lighter than transmitters used to mark American woodcock chicks in previous studies (Horton and Causey 1981, Wiley and Causey 1987). Transmitters were ≤3% of the bird's mass (BD-2NC transmitters weighed approximately 0.6 g and the BD-2C transmitters weighed approximately 1.6 g) and included an elastic collar that stretches as the juvenile grows. One end of the elastic is attached by the manufacturer, whereas the other end is loose so the transmitter can be custom-fit in the field. Based upon the neck circumference of each juvenile, the loose end is glued to the base of the transmitter to form an "expanding" collar, which is subsequently slipped over the juvenile’s head and positioned at the base of the neck with the transmitter antenna protruding down the bird's back.

We radio-marked 1-4 juveniles per brood, depending on brood size, and monitored the entire brood based on locating radio-marked juveniles. We documented mortality of juveniles and compared mortality of juveniles within the same brood that had transmitters attached to juveniles without a transmitter by counting both radio-marked and unmarked juveniles when we relocated the brood. However, because entire brood mortality may result in non-independent survival among brood mates, we also compared mortality of juveniles with transmitters with mortality of juveniles that did not have transmitters attached in broods for which the female was radio-marked. We visually assessed juvenile woodcock when we relocated them, and recorded any obvious signs of negative transmitter effects such as entanglement or feather or skin wear.

We assessed survival between radio-marked and non-radio-marked juvenile woodcock using the logistic-exposure method (Shaffer 2004). We assessed the effects of radio-transmitters on juvenile woodcock using a categorical variable indicating whether a juvenile was radio marked. We assessed a main brood effect against a null constant-survival model to test for interdependency among survival of juveniles within the same brood. We identified models best-supported by our data based on Akaike's Information Criteria with a correction factor for small samples sizes (AICc; Burnham and Anderson 2002). We defined competing models as those with the lowest AICc value ("top model," ΔAICc =0) and any model within ΔAICc ≤ 2 of the best-supported model.

RESULTS

In this report, we only present results (*by objective*) of our research project at Tamarac NWR.

1) Assess response of displaying male American woodcock to BMPs at the demonstration-area scale by comparing abundance of displaying male American woodcock on 3 demonstration areas with abundance in the surrounding landscape, as measured by routes that are part of the American Woodcock SGS.

We established six singing-ground survey routes at Tamarac NWR following the SGS protocol (Cooper and Rau 2013). In 2011, we detected a mean of 6.3 male woodcock per route, which is similar to abundance on the six official SGS routes in closest proximity to Tamarac NWR ($\bar{x}$ = 6.3) and to all routes in the state of Minnesota ($\bar{x}$ = 6.8) that were surveyed in 2011. The mean count for SGS routes does not include routes that are in constant zero status or routes that were not surveyed in 2011. The mean number of males detected per route for the Central Management Region in 2011 was 2.8.

In 2012, we detected a mean of 6.7 male woodcock per route at Tamarac NWR, which is greater than the abundance on the six official SGS routes in closest proximity to Tamarac NWR ($\bar{x}$ = 4.6) and similar in abundance to all routes in the state of Minnesota ($\bar{x}$ = 6.4) that were surveyed in 2012. The mean count for SGS routes does not include routes that are in constant zero status or routes that were not surveyed in 2012. The mean number of males detected per route for the Central Management Region in 2012 was 4.7.

2) Evaluate radio-telemetry as a tool to measure female woodcock response to application of BMPs at the demonstration-area scale.

During the 2011 and 2012 field seasons we captured 529 woodcock, including 41 adult female woodcock that we radio-marked. We banded all woodcock captured with U.S. Geological Survey aluminum leg bands (size 3). We captured female woodcock during all stages of reproduction, including pre-nesting, nesting, and brood rearing. We radio-tracked 23 females over varying periods beginning 7 April 2011 and ending 27 July 2011, and most females (*n* = 21) remained on Tamarac NWR after capture. We radio-tracked 18 females over varying periods beginning 21 March and ending 27 June 2012, and all of these females remained at Tamarac NWR after capture. Females were consistently located in managed areas throughout the breeding season.

3) Estimate adult female survival, nest success, and brood survival and relate these parameters to habitat variables at each demonstration site.

Female survival.—From 9 April to 1 June 2011 and 22 March to 24 May 2012 we captured and radio-marked 41 adult female woodcock (2011, *n* = 23; 2012, *n* = 18). We excluded three (~7%) radio-marked adult female woodcock in 2011 from survival analysis that we were unable to relocate following radio marking (likely due to transmitter failure or migration). Of the remaining 38 females we right censored one female that became entrapped in the radio telemetry harness in 2012.

In total, we observed 692 intervals and 2,149 exposure days. Intervals averaged 3.1 days between relocations and ranged from 1 day to 40 days. Seven of 38 (~18%) adult females were depredated during our study (2011, *n* = 4; 2012, *n* = 3). Mammalian predation was the highest source of mortality (57%), with the remainder attributed to raptors. Mortalities of females occurred during pre-nesting (*n* = 2), nesting (*n* = 2), brood rearing (*n* = 1), and pre-migration periods (*n* = 2). Apparent survival of females was nearly constant across reproductive stages (pre-nesting = 90.9% (DSR = 0.995), nesting = 91.3% (DSR = 0.996), brood rearing = 95.7% (DSR = 0.996), and pre-migration = 93.5% (DSR = 0.998)).

Our best-supported model of adult female woodcock survival was the null model (Table 1), suggesting that female survival was relatively constant between 2011 and 2012 and over the conditions we observed during our study. We constructed our base model to include only YEAR so we could account for differences in survival between 2011 and 2012 even though survival was similar between years ($\beta_{2011} = -0.16$, 95% CI = −1.67 to 1.45). Models that included MINT, MAXT, and PCPT were competitive with our top model; however, we considered these covariates to be uninformative because they did not reduce AICc by >2 (Arnold 2010, Table 1). Because there was no evidence to suggest that REPR was related to female woodcock survival (Table 1), we did not assess the relationship(s) between female survival and NEST and BROOD in post hoc analyses.

Daily survival rate (DSR) derived from our best-supported model of adult female woodcock survival was 0.995 (95% CI: 0.749 – 0.999) in 2011 and 0.997 (95%: CI 0.952 – 1.00) in 2012. Period survival of adult females during the breeding season for woodcock (1 April 1 to 31 July) was 0.560 (95% CI: 0.00 – 0.983) in 2011 and 0.665 (95% CI: 0.002 – 0.973) in 2012.

Table 1. Stepwise model-selection results and *a priori* models of American woodcock adult female survival at Tamarac National Wildlife Refuge, Rochert, Minnesota in 2011 and 2012. Survival related to year (YEAR; 2011 or 2012), reproductive status (REPR; pre-nesting, incubating, brood-rearing, or pre-migration), maximum and minimum temperature (MAXT and MINT), and precipitation (PCPT). Models were ranked according to the difference in Akaikie's information criterion (ΔAIC_c) corrected for small effective sample size (*n* = 2,091 intervals) within steps. Akaike model weights (ω_i) and number of estimable parameters (K) are presented for each model. Null model includes only an intercept and no covariates and is presented as reference. Stepwise model development started with an initial model including only a YEAR covariate. Step two included the addition of the REPR covariate and step three included the addition of weather-related covariates.

Model step	Model	AIC_c	ΔAIC_c	ω_i	K
	Null	71.21	--	--	1
Initial model:					
	YEAR	73.15	--	--	2
Step two:					
	YEAR [a]	73.15	0.00	0.92	2
	YEAR+REPR	78.06	4.91	0.08	6
Step three:					
	YEAR [b]	73.15	0.00	0.29	2
	YEAR+MINT	73.74	0.59	0.21	3
	YEAR+PCPT	74.89	1.74	0.12	3
	YEAR+MAXT	75.11	1.96	0.11	3
	YEAR+MINT+PCPT	75.27	2.12	0.10	4
	YEAR+MAXT+MINT	75.61	2.46	0.08	4
	YEAR+MAXT+PCPT	76.64	3.49	0.05	4
	YEAR+MAXT+MINT+PCPT	77.27	4.12	0.04	5

[a] Indicates best-supported model for each *a priori* step, model moved on to next step in analysis.

[b] Indicates best-supported overall model; AIC_c of top-ranked model = 73.15.

Nest survival.—From 4 May to 11 June 2011 and from 9 April to 9 June 2012 we monitored 52 woodcock nests (2011, *n* = 25; 2012, *n* = 23). We excluded four nests from analysis because we lacked associated covariate data. We recorded a total of 21 nest failures (44%) over 261 intervals and 630 exposure days resulting in an effective sample size of 548 exposure days. Apparent nest survival was 36.4% (8 of 22 nests) in 2011 and 69.6% (16 of 23 nests) in 2012. The majority (71%) of nests failed due to predation and the remaining nests failed due to abandonment by the female.

Our best-supported model of nest survival included only YEAR, with no difference in survival between 2011 and 2012 ($\beta_{2011} = -0.768$, 95% CI = −1.70 to 0.166). Addition of other covariates in model development did not result in competitive models and no other covariates were informative (Arnold 2010, Table 2).

Our estimate of daily survival of woodcock nests was 0.978 (95% CI: 0.811 – 0.998) in 2011 and 0.987 (95% CI: 0.957 – 0.996) in 2012. Nest survival for the period including four days to lay eggs and 21 days of incubation was 0.069(95% CI: 0.000 – 0.774) in 2011 and 0.197 (95% CI: 0.005 – 0.613) in 2012.

Table 2: Stepwise model-selection results and *a priori* models of American woodcock nest survival at Tamarac National Wildlife Refuge, Rochert, Minnesota in 2011 and 2012. Survival related to year (YEAR; 2011 or 2012), nest age (NAGE), nest initiation date (INIT), maximum and minimum temperature (MAXT and MINT), precipitation (PCPT), stem density (STEM), basal area (BAS), and distance to edge (EDGE). Models were ranked according to the difference in Akaikie's information criterion (ΔAIC_c) corrected for small effective sample size (*n* = 548). Akaike model weights (ω_i), and number of estimable parameters (K) are also presented. Null model includes only an intercept and no covariates and is presented as reference. Stepwise model development started with an initial model including only a YEAR covariate. Step two included the addition of the AGE and INIT covariates, step three included the addition of weather-related covariates, and step four included the addition of vegetative structure covariates.

Model step	Model	AIC_c	ΔAIC_c	ω_i	K
	Null	141.66	--	--	1

Initial model:					
	YEAR	140.95	--	--	2
Step two:					
	YEAR [a]	140.95	0.00	0.48	2
	YEAR+NAGE	142.38	1.43	0.24	3
	YEAR+INIT	142.81	1.86	0.19	3
	YEAR+NAGE+INIT	144.29	3.34	0.09	4
Step three:					
	YEAR [a]	140.95	0.00	0.27	2
	YEAR+MAXT	141.88	0.93	0.17	3
	YEAR+MAXT+MINT	142.33	1.38	0.13	4
	YEAR+MINT	142.41	1.46	0.13	3
	YEAR+PCPT	142.46	1.68	0.12	3
	YEAR+MAXT+PCPT	143.74	2.79	0.07	4
	YEAR+MINT+PCPT	143.82	2.87	0.06	4
	YEAR+MAXT+MINT+PCPT	144.23	3.27	0.05	5
Step four:					
	YEAR [b]	140.95	0.00	0.29	2
	YEAR+STEM	141.48	0.53	0.22	3
	YEAR+EDGE	142.86	1.91	0.11	3
	YEAR+BAS	142.93	1.98	0.11	3
	YEAR+STEM+EDGE	143.06	2.11	0.10	4
	YEAR+STEM+BAS	143.34	2.39	0.09	4
	YEAR+BAS+EDGE	144.86	3.91	0.04	4
	YEAR+STEM+BAS+EDGE	144.94	3.99	0.04	5

[a] Indicates best-supported model for each *a priori* step, model moved on to next step in analysis.

[b] Indicates best-supported overall model, AIC_c of top-ranked model = 140.95.

Juvenile survival.—From 16 May to 29 June 2011 and 20 April to 16 June 2012 we radio-marked 73 (2011, *n* = 22; 2012, *n* = 51) juvenile American woodcock from 51 broods (*n* = 16 in 2011 and *n* = 35 in 2012). We knew fates of 134 juvenile woodcock (2011, *n* = 63; 2012, *n* = 71), including fates from 49 marked and 85 unmarked juveniles from 47 broods (2011, *n* = 23; 2012, *n* = 24), resulting in an effective sample size of 859 observation intervals. We excluded data from 24 marked juvenile woodcock due to uncertainty regarding radio failure (i.e., we did not know if the radio failed or if the juvenile was depredated). Over the two years of our study, apparent survival of juveniles was 0.75 (*n* = 134). Apparent survival of juveniles was 0.70 (*n* = 64) in 2011 and 0.79 (*n* = 72) in 2012.

Our best-supported model of juvenile woodcock survival included YEAR, JAGE, MINT, and PCPT (Table 3). In our best-supported model, 95% confidence intervals around coefficient estimates for YEAR ($\beta_{2011}= -0.85$, 95% CI = −1.77 to 0.07) and MINT ($\beta_{\mathrm{MINT}} = 0.14$, 95% CI = −0.004 to 0.28) included zero, indicating no statistically significant relationship with survival of juvenile woodcock (Table 3). JAGE ($\beta_{\mathrm{AGE}} = 0.098$, 95% CI = 0.04 to 0.16) was positively associated with juvenile survival and PCPT ($\beta_{\mathrm{PCPT}} = -0.20$, 95% CI = −0.39 to −0.01) was negatively associated with juvenile woodcock survival.

Estimated daily juvenile woodcock survival based on our best-supported model, and holding PCPT, MINT, and JAGE at their mean values for each year was 0.981 (95% CI: 0.482 – 1.000) in 2011 and 0.992 (95% CI: 0.845 – 1.000) in 2012. Juvenile survival for the period 1 May to 31 July was 0.173 (95% CI: 0.000 – 0.969) in 2011 and 0.470 (95% CI: 0.000 – 0.966) in 2012. Juvenile DSR decreased approximately 0.007 for each additional cm of precipitation and DSR increased approximately 0.002 for each additional day of age up to 15 days old.

We considered covariates related to vegetation structure in our post hoc analysis of juvenile survival. STEM was the only vegetation structure covariate to decrease AICc when added to our best-supported model based on our stepwise *a priori* analysis. STEM had a positive relationship with juvenile woodcock survival ($\beta_{\mathrm{STEM}} = 0.0001$, 95% CI = −0.000 to 0.0003). Juvenile daily survival increased asymptotically with stem density, resulting in a slight increase in DSR of 0.006 for every additional 10,000 stems/ha.

Table 3: Stepwise model-selection results and *a priori* models of juvenile American woodcock survival at Tamarac National Wildlife Refuge, Rochert, Minnesota in 2011 and 2012. Survival related to year (YEAR; 2011 or 2012), juvenile age (JAGE), hatch date (HD), maximum and minimum temperature (MAXT and MINT), precipitation (PCPT), stem density (STEM), basal area (BAS), and distance to edge (EDGE). Models were ranked according to the difference in Akaikie's information criterion (ΔAIC_c) corrected for small effective sample size (*n* = 1,754). Akaike model weights (ω_i), and number of estimable parameters (K) are also presented. Null model includes only an intercept and no covariates and is presented as reference. Stepwise model development started with an initial model including only a YEAR covariate. Step two included the addition of the AGE and HD covariates, and step three included the addition of weather-related covariates.

Model step	Model	AIC_c	ΔAIC_c	ω_i	K
	Null	245.59	--	--	1
Initial model:					
	YEAR	247.10	--	--	2
Step two:					
	YEAR+JAGE [a]	238.83	0.00	0.54	3
	YEAR+JAGE+HD	240.76	1.93	0.20	4
	YEAR+JAGE+HD+(HD×YR)	241.87	3.04	0.12	6
	YEAR+JAGE+(HD×YR)	241.86	3.04	0.12	5
	YEAR	247.10	8.27	0.01	2
	YEAR+HD	248.04	9.22	0.01	3
	YEAR+HD+(HD×YR)	248.15	9.32	0.01	5
	YEAR+(HD×YR)	248.15	9.32	0.01	4
Step three:					
	YEAR+JAGE+MINT+PCPT [b]	235.03	0.00	0.28	5
	YEAR+JAGE+MAXT+MINT+PCPT	235.57	0.54	0.21	6
	YEAR+JAGE+MAXT+PCPT	236.22	1.19	0.15	5
	YEAR+JAGE+PCPT	236.81	1.78	0.11	4
	YEAR+JAGE+MINT	236.85	1.82	0.11	4

YEAR+MAXT+MAXT+MINT	238.22	3.19	0.06	5
YEAR+JAGE	238.83	3.80	0.04	3
YEAR+MAXT	239.38	4.35	0.03	4

[a] Indicates best-supported model for each *a priori* step, model moved on to next step in analysis.

[b] Indicates best-supported overall model, AICc of top-ranked model = 235.03.

4) Estimate recruitment using night-lighting and mist net capture techniques on summer roosting fields at demonstration areas, and evaluate these techniques as a means to assess recruitment.

In 2011, our estimates of recruitment indices through early August varied considerably as a function of capture technique. We captured 3.50 juveniles per adult female (*n* = 87) via mist netting, and 1.46 juveniles per adult female (*n* = 42) via night-lighting (Table 4). We captured more woodcock using mist netting than night lighting, in part because night lighting is only effective under very specific weather conditions. We spent a total of 16 hours and 20 minutes mist netting and a total of 23 hours and 30 minutes night lighting between 7 July and 24 July 2011. Trapping effort for mist netting totaled 114 trap nights, which is the number of mist nets per night multiplied by the number of nights mist nets were set. An average of 9.5 mist nets was set per night. Each night during night-lighting, we had a single person shinning a spot light and one to two people attempting to capture woodcock with long-handled nets. Capture rate for mist netting on summer roosting field was 5.3 woodcock captured per hour, whereas the capture rate for night lighting on roosting fields was 1.8 woodcock captured per hour. Our estimate of recruitment based on survival and reproduction of females and survival of chicks was 0.62 juveniles per adult female, considerably lower than the index derived from either capture technique.

Our summer capture results from 2012 were similar to those from 2011 (Table 4). We captured 2.28 juveniles per adult female (*n* = 117) via mist netting, and 0.38 juveniles per adult female (*n* = 27) via night-lighting (Table 1). We spent a total of 39 hours and 59 minutes mist netting and 29 hours night-lighting between 1 July and 30 July 2012, resulting in a capture rate of 2.92 woodcock per hour mist netting and 0.93 woodcock per hour night-lighting. Trapping effort for mist netting totaled 220 trap nights with an average of 10.5 mist nets set per night. Our estimate of recruitment based on survival and reproduction of females and survival of chicks was 0.28 juveniles per adult female.

Table 4. Comparison of summer capture techniques in 2011 and 2012 and associated recruitment ratios.

Capture method	Adult male	Adult female	Immature male	Immature female	Recruitment ratio
2011					
Mist netting	24	14	39	10	3.50
Night lighting	10	13	14	5	1.46
2012					
Mist netting	35	25	41	16	2.28
Night lighting	9	13	2	3	0.38

5) Develop and assess techniques for radio-marking American woodcock chicks to estimate juvenile survival and document brood habitat use.

During 2011 and 2012 we radio-marked 73 (*n* = 22 in 2011 and *n* = 51 in 2012) juvenile American woodcock from 51 broods (*n* = 16 in 2011 and *n* = 35 in 2012). We knew fates of 49 marked and 79 unmarked juveniles from 45 broods, giving us an effective sample size of 1,041 observation intervals. Due to uncertain times of radio failure we were unable to ascertain fates of 24 marked juveniles and censored these juveniles from analysis.

We did not observe instances of negative impacts (i.e., entrapment in radio harness, or skin or feather wear) of radio transmitters on juvenile woodcock during the course of our study. We found no evidence of non-independence among juveniles within the same brood ($\chi_{44}^2 = 17.15$, $P = 0.99$), and we therefore treated all individuals' fates in our sample as independent. Our best-supported model of juvenile woodcock survival included the interaction of AGE × YR and the additive effect of PCPT (Table

2). PCPT had a negative relationship with juvenile survival ($\beta_{PCPT} = -0.76$, 85% CI = −1.08 to −0.43). Although TRANS, MINT, and MAXT all appeared in survival models competitive with our best-supported model ($\Delta AIC_c \leq 2$), these variables were uninformative as they did not decrease the overall AIC_c by ≥ 2 when they were added as an additional covariate; therefore, we did not consider models including these covariates to be competitive with our best-supported model. There was no evidence to suggest that either TRANS or HD was related to juvenile woodcock survival (Table 2).

We calculated daily survival rates (DSR) of juvenile woodcock using our best-supported model, holding PCPT constant at the mean value ($\bar{x} = 0.19$) and allowing AGE and YR to vary across each combination of AGE and YR combination (Fig. 1). The effect of the AGE × YR interaction was approximately zero in 2011 ($\beta_{YR \times AGE}$ for 2011 = −0.01), but was positive in 2012 ($\beta_{YR \times AGE}$ for 2012 = 0.12). We calculated cumulative survival for 2011 and 2012 separately as the product of each age-specific DSR (1-15 days) for that year. Cumulative (15-day interval) survival of juvenile woodcock was 0.617 (95% CI: 0.030 – 0.941) in 2011 and 0.865 (95% CI: 0.228 – 0.986) in 2012.

To assess the relationships between PCPT, AGE, and YR we allowed the value of the covariate of interest to vary in our best-supported model while simultaneously holding the other covariates constant at their mean values. Daily survival decreased with the amount of precipitation, resulting in an average decrease of approximately 0.01 in juvenile DSR for each additional cm of precipitation. Juvenile DSR increased asymptotically with AGE, resulting in a 0.002 average increase in DSR with each additional day of age up to 15 days old.

PCPT was the only weather covariate in our best-supported model. However, because the distribution of PCPT across intervals was highly skewed (many zero precipitation events and few relatively high precipitation events), we evaluated both the relationship between juvenile survival and PCPT using only intervals with PCPT below extreme levels (<7.5 cm) and between juvenile survival and PCPT when PCPT was extreme. With PCPT <7.5 cm, juvenile DSR declined an average of 0.008 per cm of precipitation ($\beta_{PCPT0<i<7.5} = -0.71$, SE = 0.46). In contrast, juvenile DSR decreased an average of 0.03 per cm of precipitation when PCPT during the interval was >7.5 cm.

Table 5: Model-selection results from *a priori* analysis of American woodcock juvenile survival at Tamarac National Wildlife Refuge, Rochert, Minnesota in 2011 and 2012. We considered models of survival related to age (AGE; 1-15days), year (YR; 2011 or 2012), hatch date (HD; Julian date), precipitation (PCPT), maximum and minimum temperature (MAXT and MINT), and transmitters (TRANS). Models were ranked according to the difference in Akaikie's information criterion (ΔAIC_c) corrected for small effective sample size (n = 1,041 intervals), Akaike model weights (ω_i), and number of estimable parameters (K).

Model[a]	ΔAIC_c	ω_i	K
(YR×AGE) + PCPT	0.00	0.38	4
(YR×AGE) + PCPT + MINT	1.36	0.19	5
(YR×AGE) + PCPT + TRANS	1.78	0.16	5
(YR×AGE) + PCPT + MAXT	1.91	0.15	5
(YR×AGE) + PCPT + MAXT + MINT	3.06	0.08	6
(YR×AGE)	6.97	0.01	3
(YR×AGE) + HD	7.30	0.01	4
(YR×AGE) + MINT	7.83	0.01	4
YR + AGE	8.12	0.01	3
(YR×AGE) + MAXT	8.54	0.01	4
(YR×AGE) + MAXT + MINT	8.88	0.00	5
(YR×AGE) + (YR×HD)	8.98	0.00	5

[a] AIC_c of top-ranked model = 182.01

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Appedix A

Covariates used in logistic-exposure analysis of survival of American woodcock females, juveniles, and nests at Tamarac National Wildlife Refuge, Minnesota in 2011 and 2012, symbol, model(s) which the covariate was included, and explanation of relationship between covariate and survival.

Covariate	Symbol	Model(s)	Relationship to survival
Basal area	BAS	Nest and Juvenile	Woodcock choose areas with relatively low basal area (Sepik and Dwyer 1982, McAuley et al. 1996, Dessecker and McAuley 2001). Areas with greater basal area provide a greater number of perches for raptors and therefore we hypothesize basal area to have a negative relationship with juvenile and nest survival.
Distance to edge	EDGE	Nest and Juvenile	Nest survival decreases with distance to edge (Manolis et al. 2002) therefore we hypothesize distance to edge to have a positive relationship with nest survival. Edges also provide travel corridors for mammalian predators and areas of high visibility and perches for raptors; therefore, we hypothesize distance to edge and juvenile survival to have a positive relationship (Gregg 1984).
Hatch date	HD	Juvenile	Juveniles that hatch earlier are more likely to be from the females in the best condition (Blums et al. 2005) therefore we hypothesize that hatch date is negatively associated with juvenile survival.
Initiation date	INIT	Nest	Nests initiated earlier in the season experience higher survival than nest initiated later for many species (Newlon and Saab 2011), therefore, we hypothesize nest initiation date to have a negative relationship with nest survival.
Juvenile age	JAGE	Juvenile	Survival likely asymptotically increases with age of the juvenile because they are better able to thermoregulate as they age (Rabe et al. 1983) and likely most vulnerable to predation soon after leaving the nest (Streby and Andersen 2013), therefore we hypothesized a positive relationship

			with age and juvenile survival.
Maximum temperature	MAXT	Female, Nest, and Juvenile	Maximum temperature is related to the thermoregulatory abilities of woodcock. Higher maximum temperatures likely increase survival of females during incubation and brood rearing (Rabe et al. 1983, Longcore et al. 2000), therefore we hypothesize maximum temperature to have a positive relationship with female survival. Due to the hypothesized positive relationship between female survival and maximum temperature, and the inability for juveniles to properly thermoregulate early in life (Rabe et al. 1983), we also hypothesize maximum temperature to have a positive relationship with nest and juvenile survival due to higher associated female survival during nesting and brood rearing.
Minimum temperature	MINT	Female, Nest, and Juvenile	Lower minimum temperatures restrict the ability of woodcock to thermoregulate (Rabe et al, 1983) and may restrict food availability (Vander Haegan et al. 1993) may have negative impacts on survival; therefore we hypothesize minimum temperature to have a positive relationship with female and juvenile survival. Because of the hypothesized relationship with female survival and minimum temperature, we also hypothesize minimum temperature to have a positive relationship with nest survival.
Nest age	NAGE	Nest	Survival asymptotically increases with nest age, therefore we hypothesize that nest age has a positive relationship with nest survival.
Precipitation	PCPT	Female, Nest, and Juvenile	Precipitation hinders the ability of woodcock to thermoregulate (Rabe et al. 1983) and has been negatively related to juvenile woodcock survival (Dwyer et al. 1988) and therefore we hypothesize that precipitation is negatively associated with female and juvenile survival. High amounts of precipitation can also cause nests to flood in low laying areas or females to abandon nests and thus decrease nest survival. We hypothesize precipitation to have a negative

			relationship with nest survival.
Reproductive status [a]	REPR	Female	Energetic requirements and behavior of adult females differ depending on reproductive stage (Rabe et al. 1983). High energetic costs during nesting and incubation and the females' association with the nest can make the female more vulnerable to predation. Brood rearing can also make females more vulnerable due to sharing of food resources and tending to juveniles (Rabe et al. 1983). For these reasons, we hypothesize survival should be higher when females are not associated with a nest or brood.
Stem density	STEM	Nest and Juvenile	Woodcock select areas with high stem densities (Sepik and Dwyer 1982, McAuley et al. 1996, Dessecker and McAuley 2001) that provide thermoregulatory cover for juvenile and predatory cover for juveniles and nests. We hypothesize areas with higher stem densities have a positive association with juvenile and nest survival.
Year [a]	YEAR	Female, Nest, and Juvenile	Woodcock survival has been shown to differ between years (Gregg 1984, Longcore et al. 2000, McAuley et al. 2010). We included year in our analysis to account for temporal variation in survival of females, juveniles and nests.

[a] Indicates a categorical variable.